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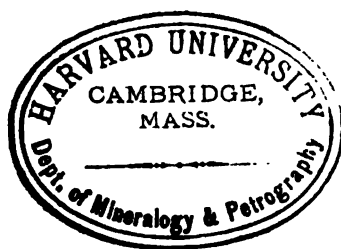
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Bulletin 641

CONTRIBUTIONS TO ECONOMIC GEOLOGY

(SHORT PAPERS AND PRELIMINARY REPORTS)—

1916

PART II.—MINERAL FUELS

DAVID WHITE, G. H. ASHLEY, AND M. R. CAMPBELL

GEOLOGISTS IN CHARGE



WASHINGTON

GOVERNMENT PRINTING OFFICE

1917

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NOTE.—The Survey's annual volumes entitled "Contributions to economic geology" are issued in parts, and the last part will include a volume title-page, table of contents, and index for the use of those who may wish to bind the separate parts. A small edition of the bound volume will also be issued, but copies can not be supplied to those who have received all the parts.

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PART II. MINERAL FUELS.

DAVID WHITE, M. R. CAMPBELL, and G. H. ASHLEY,
Geologists in charge.

INTRODUCTION.

The Survey's "Contributions to economic geology" have been published annually since 1902. In 1906 the increase in the number of papers coming under this classification made it necessary to divide the contributions into two parts, one including papers on metals and nonmetals except fuels and the other including papers on mineral fuels. In 1915 the year included in the title was changed from the year in which the field work reported in these papers was done to the year of publication, and in consequence there was no volume entitled "Contributions to economic geology, 1914." The subjoined table gives a summary of these bulletins.

United States Geological Survey "Contributions to economic geology."

Date in title.	Date of publication. ^a	Bulletin No.	Date in title.	Date of publication. ^a	Bulletin No.
1902.....	1903	213	1910, Part I.....	1911	470
1903.....	1904	225	Part II.....	1912	471
1904.....	1905	260	1911, Part I.....	1913	530
1905.....	1906	285	Part II.....	1913	531
1906, Part I.....	1907	315	1912, Part I.....	1914	540
Part II.....	1907	316	Part II.....	1914	541
1907, Part I.....	1908	340	1913, Part I.....	1915	580
Part II.....	1908	341	Part II.....	1915	581
1908, Part I.....	1909	380	1915, Part I.....	1916	620
Part II.....	1910	381	Part II.....	1916	621
1909, Part I.....	1910	430	1916, Part I.....	1917	640
Part II.....	1911	431	Part II.....	1917	641

^a The date given is that of the complete volume; beginning with Bulletin 285 the papers have been issued as advance chapters as soon as they were ready.

As the subtitle indicates, the papers included in these volumes, are of two classes—(1) short papers giving comparatively detailed descriptions of occurrences that have economic interest but are not of

sufficient importance to warrant a more extended description; (2) preliminary reports on economic investigations the results of which are to be published later in more detailed form. These papers are such only as have a direct economic bearing, all topics of purely scientific interest being excluded.

Brief abstracts of the publications of the year are given in the annual report of the Director. The complete list of Survey publications affords, by means of finding lists of subjects and of authors, further aid in ascertaining the extent of the Survey's work in economic geology.

The reports on work in Alaska have been printed in a separate series since 1904, the volumes so far issued being Bulletins 259, 284, 314, 345, 379, 442, 480, 520, 542, 592, 622, and 642.

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 641—A

OZOKERITE IN CENTRAL UTAH

BY

HEATH M. ROBINSON

Contributions to economic geology, 1916, Part II

(Pages 1-16)

Published June 12, 1916



WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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OZOKERITE IN CENTRAL UTAH.

By **HEATH M. ROBINSON.**

INTRODUCTION.

The American needs for ozokerite (a substance commonly known as mineral wax) have been largely met in the past by imports from the Galician mines in Austria, but recently interest in the domestic supply of this material has been stimulated. In order to obtain information regarding the supply of ozokerite in Utah, where the principal deposits in this country are situated, the writer spent about a week in September, 1914, in an examination of the best-known localities in the central part of the State. The work was materially aided by the ready assistance of those living in the neighborhood, but more particularly of the officials of the American Ozokerite Co., who kindly furnished maps and other data.

THE OZOKERITE FIELD.

The largest district in the United States in which ozokerite has been mined and prospected is an area in central Utah a little more than 12 miles long and from 1 to 4 miles wide. The index map on Plate I (p. 16) shows the location of this field. It includes parts of T. 10 S., Rs. 7 and 8 E., and T. 11 S., Rs. 8 and 9 E., Salt Lake base and meridian, in Utah and Wasatch counties.

The main line of the Denver & Rio Grande Railroad borders the ozokerite field on the southwest, and as this field is only from 1 to 4 miles wide, all the mines and prospects are within short distances of railroad facilities. Wagon roads have been built from many of the mines and prospects to shipping points on the railroad. As the mines have not been continuously worked many of these roads have been little used and were found to be in poor condition at the time the field was examined.

Colton, the largest town in the ozokerite area, Soldier Summit, and Gilluly are on the main line of the Denver & Rio Grande Railroad. Soldier Summit is on the crest of the Wasatch Plateau. West of the summit the drainage goes into Soldier Fork, whose waters flow into the valley of Utah Lake; east of the divide the waters empty

into Price River, the principal stream in the area, which is part of the Colorado River drainage system. Price River heads in the mountains north and east of Soldier Summit and flows in a southeasterly direction past the town of Colton and thence beyond the limits of the field. The altitude of Colton is 7,188 feet, of Soldier Summit 7,440 feet, and portions of the field attain an altitude of 8,000 feet, the maximum relief being therefore more than 800 feet. The ozokerite area is bounded on the northeast by the Roan Cliffs, which extend eastward well into Colorado and have in many localities outside of this field a relief between 2,000 and 3,000 feet. The country north of these cliffs is plateau-like and slopes gently toward the north. The topography southwest of the ozokerite field is largely influenced by the geologic structure, which produces long, gradual dip slopes. Price River in this area flows on soft shale for the most part and consequently has a relatively broad valley.

HISTORY OF DISCOVERY AND DEVELOPMENT.

The first prospecting in this field is said to have been done about 1886 in the vicinity of the old railway station at Media, 3 miles west of Soldier Summit. However, as early as 1879 samples of ozokerite or allied substances which came from Utah were analyzed, and at that time there was much discussion concerning their chemical properties.¹ In 1885 Clayton² discussed the Utah ozokerite deposits and also mentioned the associated bituminous shale. Gosling,³ in a publication dated 1895, treated of the properties of ozokerite and of its occurrences and gave a good bibliography of the subject up to the date of his paper. Eldridge⁴ in 1901 mentioned ozokerite as a thin vein crossing the stratification and in small pockets lying with the bedding. The most detailed report that has been published on Utah ozokerite is that of Taff and Smith,⁵ which gives a concise description of the field near Soldier Summit and Colton, with descriptions of three samples from different localities and of the development of the field at the time of their examination.

GEOLOGY.

STRATIGRAPHY.

General features.—The rocks of this field have a total thickness of about 4,000 feet and were deposited as nonmarine sediments in early Tertiary (Eocene) time. The lower 1,000 feet of beds exposed, as

¹ Newberry, J. S., *Mineral wax*: Eng. and Min. Jour., vol. 27, p. 71, 1879. Wurts, Henry, *The Utah mineral wax*: Idem, pp. 108, 109. Newberry, S. B., *Utah mineral wax*: Idem, p. 199.

² Clayton, J. E., *Ozokerite or mineral wax*: Eng. and Min. Jour., vol. 39, pp. 168, 169, 1885.

³ Gosling, E. B., *A treatise on ozokerite*: School of Mines Quart., vol. 16, pp. 41-68, 1895.

⁴ Eldridge, G. H., *The asphalt and bituminous rock deposits of the United States*: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, p. 361, 1900-1901.

⁵ Taff, J. A., and Smith, C. D., *Ozokerite deposits in Utah*: U. S. Geol. Survey Bull. 285, pp. 369-372, 1905.

outlined on Plate I, are known to contain ozokerite, and the remaining 3,000 feet, exposed to the northeast, contain bituminous or oil shale interbedded with other rocks. On the basis of this distinction two stratigraphic units may be recognized, and on lithologic resemblances to formations in other areas tentative correlations may be made. The lower beds, which do not contain oil shale, are of Wasatch age, and the upper or younger strata, which contain oil shale, are of Green River age.

Three small fossil collections, from points indicated by F1, F2, and F3 on Plate I, have been examined by W. H. Dall, who identified the following species:

Collection No. F1, NW. $\frac{1}{4}$ sec. 14, T. 11 S., R. 8 E.:

Physa pleuromatis White.

Goniobasis nodulifera Meek.

Planorbis sp. cf. *P. parvus* Say.

Unio like *U. shoshonensis* White.

Fragments of *Anodonta* sp.

Collection No. F2, NE. $\frac{1}{4}$ sec. 21, T. 10 S., R. 7 E.:

Vivipara cf. *V. wyomingensis* White.

Goniobasis nodulifera Meek.

Unio sp., fragments.

Collection No. F3, SE. $\frac{1}{4}$ sec. 24, T. 10 S., R. 7 E.:

Vivipara wyomingensis? White.

Planorbis sp. near *P. tuneus* Carpenter.

Physa pleuromatis? White.

Goniobasis nodulifera Meek.

Fragments of *Unio* sp. and *Anodonta* sp.

From these data Mr. Dall concludes that the age of the beds is Eocene.

Wasatch formation.—The principal ozokerite mines and prospects have been opened in the Wasatch formation and are scattered irregularly through a stratigraphic distance of 600 to 700 feet. The base of the formation is not exposed in the ozokerite field, but the part that crops out is about 1,000 feet thick. The rocks consist of shale, sandstone, and limestone. The shale is tinted purple, green, and red in different beds, and all gradations exist between sandy shale and sandstone. The sandstone is brown and shows lenticular bedding. The limestone beds are thin and are sparsely distributed through the section.

The major portion of the formation is made up of sandy shale and sandstone, which occur in alternate beds 1 to 10 feet in thickness. Inasmuch as the extent and character of the fissures in sedimentary rocks depend more or less on the kind of rock, the alternation of sandstone with shale beds has caused an irregular distribution of ozokerite, which fills many of the fissures.

Green River formation.—The lowest beds of the Green River formation border the northeast side of the ozokerite field, and the for-

mation is extensively developed in the area north of that outlined on Plate I. This formation consists of shale and sandstone interbedded with a small amount of limestone and has a thickness of about 3,000 feet. Much of the shale is bituminous and yields oil on destructive distillation. The formation as a unit is gray on weathered outcrops, and it is more evenly bedded and persistent than the underlying Wasatch formation.

STRUCTURE.

The rocks in the ozokerite field dip 1° – 25° N., forming a portion of the south limb of the great Uinta Basin syncline. The symbols on the map (Pl. I) show the strike and dip of the beds at a number of places in the field. The rocks are broken by a system of joints and small faults, and zones of brecciated or crushed rock are common. Most of the joint planes are vertical or nearly so, and the most common direction for the principal system of fissures is N. 10° W. There is a minor system of fissures at angles of 60° – 90° with the major system. Although small faults are common, no fault with a vertical displacement in excess of 10 feet was found in the examination of the surface and underground exposures. The fault planes dip at an angle of 45° , and slickensided surfaces are common. The fracture planes and zones are important, inasmuch as the ozokerite fills the cavities which have resulted from the fracturing.

OZOKERITE.

COMPOSITION AND PROPERTIES.

Ozokerite is the principal mineral resource of this immediate locality. It is a mixture of hydrocarbons¹ in various proportions, the exact nature of which is a subject of dispute. Some authors consider that it is composed of members of the paraffin series; others place its chief constituents in the olefin series. In commenting on certain experiments, Redwood² says: "The natural inference is that in addition to crystalline paraffin ozokerite contains certain colloidal substances (amorphous paraffin), the presence of which hinders the crystallization of the paraffin." In color ozokerite varies from black or dark brown to light yellow, but some specimens have a greenish color. It may be as soft as tallow or as hard as gypsum. The light-colored varieties yield the largest amounts of ceresin, the refined product. The melting point of ozokerite ranges, in general, from 58° to about 80° C., but a very few specimens have been reported to have a melting point of 100° C. Although paraffin with a melting point as high

¹ Redwood, Boverton, and Holloway, G. T., *Petroleum*, vol. 1, pp. 217 and 218, 1896.

² Redwood, Boverton, *The Galician petroleum and ozokerite industries*: Soc. Chem. Industry Jour., vol. 11, p. 114, 1892.

as that of ozokerite may be extracted from petroleum, it is not a commercial product, and the paraffin that is put on the market has a melting point considerably lower. The specific gravity ranges from about 0.85 to 0.97.¹ Ozokerite is soluble in ether, petroleum, benzine, turpentine, and carbon bisulphide.

TESTS.

The writer is indebted to Dr. David T. Day and others, of the Bureau of Mines, for the following data on tests of six samples of Utah ozokerite from localities Nos. 1, 3, 6, 10, 15, and 16. (See Pl. I, p. 16.)

Specific gravity and melting point of Utah ozokerite.

Sample No.	Specific gravity.	Melting point (°C.).	Sample No.	Specific gravity.	Melting point (°C.).
1.....	1.300+	60	10.....	0.899	62
3.....	.905	63	15.....	.915	60
6.....	.905	66	16.....	.920	79

The melting point of each sample was determined by placing a minute fragment of ozokerite in a capillary tube strapped to a thermometer and heating the apparatus in a water bath until the fragment melted, then noting the temperature. This is a tedious method but the only one that gives accurate results.

Solubility of Utah ozokerite.

Sample No.	In ether (per cent).	In benzol.	In oil of turpentine.	In petroleum.	In ethyl alcohol.
1.....	17.1	Complete ^a	Complete.....	Complete.....	(b)
3.....	46.7	Complete ^c	do.....	do.....	(b)
6.....		do.....	do.....	do.....	(b)
10.....	38.8	Complete ^a	do.....	do.....	(b)
15.....	27.9	Complete ^a	do.....	do.....	(b)
16.....	2.1	do.....	do.....	do.....	(b)

^a A little residue of limestone after benzol extraction.

^b Ceresin soluble in hot alcohol; asphalt insoluble.

^c A little residue of organic matter after benzol extraction.

The solubility tests given in the above table were made by shaking fine shavings of each sample with each solvent, then heating the mixture. Generally, much time was necessary for the solution of any considerable quantity of ceresin by any of the solvents when cold, but heating greatly increased the capacity of the solvent. As will be seen by the table, ozokerite is completely soluble in three of the five solvents used.

Ceresin is easily soluble in boiling ether, and the associated asphaltic material is only slightly soluble, a fact which renders possible

¹ Gosling, E. B., A treatise on ozokerite: School of Mines Quart., vol. 16, p. 41, 1895.

the partial separation of ceresin from asphalt. A weighed portion of each sample of ozokerite was placed in a Soxhlets extraction apparatus, and ceresin was extracted with boiling ether so long as the ether ran through without any appreciable discoloration. The solution was then evaporated and the residue weighed as ceresin. The ceresin was considerably discolored, it being impossible with ether to prevent the solution of slight amounts of asphalt.

The solubility tests suggested a possible method for the separation of ceresin from asphalt by a boiling solution of alcohol, based on the fact that ceresin is soluble and asphalt is insoluble in alcohol. A 20-gram sample of ozokerite (sample No. 6) was boiled with 300 cubic centimeters of strong ethyl alcohol (between 98 and 100 per cent pure), which dissolved a large percentage of the ceresin in the sample. After the solution was poured from the undissolved asphaltic residue and the liquid allowed to cool, most of the ceresin which it contained crystallized out white and clean, with no trace of asphalt. The alcohol solution was then cooled down to -15°C ., when a further amount of ceresin crystallized out, leaving a small amount of the oil originally present in the asphalt. By reboiling the asphaltic residue with the same alcohol and repeating this process several times it was possible to dissolve all the ceresin, making a complete separation of ceresin from asphalt. The treatment yielded 3.6 grams of oil, 8.5 grams of asphalt, and 7.9 grams (39.5 per cent) of ceresin. It is believed that by the use of a cheap though strong denatured alcohol this method of separation can be made commercially practicable. There need be very little distillation of the alcohol, it being necessary simply to boil the rock containing the ozokerite with alcohol, which may then be drawn off and allowed to cool, the ceresin will crystallize out, leaving the same alcohol suitable for repeated extractions. Finally a leaching form of this process would give ceresin in a pure and satisfactory condition.

It was thought that the last ceresin to go into solution would have a higher melting point than the portion going into solution earlier. In order to determine this matter 15 successive extractions were made from the ozokerite, and the melting points were determined for most of these extracts, as shown below:

Melting point of ceresin extracted from Utah ozokerite.

	$^{\circ}\text{C}$.		$^{\circ}\text{C}$.
Extracts 1, 2, and 3.....	50-56	Extract 10.....	66
Extracts 4 and 5.....	66	Extracts 11 and 12.....	68
Extracts 6, 7, and 8.....	65	Extract 14.....	70
Extract 9.....	68		

These figures show in a general way what was expected, namely, that the melting point of ceresin increases as the relative solubility becomes less. The increase is not constant, but the melting point

ranges from 50° C. in the most soluble to 70° C. in the least soluble portion of the ceresin. The first extracts, melting at 50° to 56°, were probably contaminated by oil, but there was not sufficient difference in the extracts of any other group to justify assuming the presence of other hydrocarbons. These results indicate that it is possible, by treatment with alcohol, to separate distinctly different grades of ceresin from a single lot of ozokerite.

The separation of asphalt from ceresin by sulphuric acid is a very tedious operation, on account of the persistent emulsions formed by the sulphuric acid and the ozokerite. A sample of crude ozokerite (sample No. 10) in the form of shavings was boiled with especially refined gasoline, varying in boiling point from 65° to 95° C. Gasoline was used in large excess, 300 cubic centimeters to 5 grams of ozokerite. The solution of gasoline containing ozokerite after cooling was treated with strong sulphuric acid (specific gravity 1.84), and after repeated agitations with the acid the gasoline solution was treated with a water wash. After washing several days at a time to break up the emulsion and remove the excess of acid, a final treatment with sulphuric acid reduced the ceresin content of the gasoline solution to 21 per cent, or in other words 21 per cent of the gasoline solution of ozokerite was ceresin.

A second and similar test with sulphuric acid was made of the residuum remaining after the distillation of the crude ozokerite (sample No. 10). The test was carried out in precisely the same manner as the one described above, and the ceresin content of the gasoline solution was reduced to 19 per cent.

It is the practice in Galicia and elsewhere to treat either molten ozokerite or ozokerite in a hot solution of gasoline or benzol with strong sulphuric acid or with fuming sulphuric acid for the purpose of extracting asphaltum, which is attacked by the acid. The ceresin is left in solution and is afterward separated by evaporation of the solvent. It appears from the experiments reported above that the separation of asphalt from ceresin by alcohol gives more satisfactory results.

Fractional distillation of Utah ozokerite.

Sample No. ^a	Began to boil (° C.).	Ceresin distilled over (cubic centimeters).				Residuum (grams).
		75°-150° C.	150°-300° C.	300°-350° C.	Total.	
3.....	80	2	10	33	45	14.9
10.....	75	1	9	30	40	9.5
15.....	83	.5	7	22	29.5	24.7

^a Each sample weighed 50 grams.

The same methods were used in the distillation of ozokerite as those in vogue for the distillation of crude petroleum. The results of these tests indicate that the greater part of the ceresin distills over

without any appreciable decomposition at moderate temperatures, but decomposition of the portion distilled at temperatures above 350° is evident. The ceresin crystallizes out, taking the form common to the paraffin of commerce, but has a higher melting point.

FORM AND CONTENT OF DEPOSITS.

The ozokerite of central Utah is found in fissures and brecciated zones caused by the fracturing of the rocks. This fracturing has produced joints and small faults, most of which are nearly vertical. The principal fissures trend about N. 10° W. and contain the largest deposits of ozokerite in the field. Brecciated zones are also common, and in these the ozokerite incloses angular fragments of country rock. The included rock fragments show little or no impregnation by the ozokerite and apparently have suffered very little movement. The ozokerite and the walls of the fissures commonly show slickensided surfaces. In the writer's examination of the deposits he observed veins of ozokerite from mere films to 6 or 8 inches in thickness, and according to Taff and Smith¹ veins nearly 3 feet thick have been found in the mines. The deposits are irregular in size, as stated by Taff and Smith:² "The extent, either in thickness or length, of the occurrence of ozokerite * * * can not be relied on far beyond the limit of prospected ground. Both the width of the fissure or fractured zone and the occurrence of ozokerite are found to be variable."

The fissures were undoubtedly produced by movement in the rocks prior to the deposition of the ozokerite, but the slickensided condition of some of the ozokerite indicates that movement has taken place since the fissures were filled.

The lenticular nature of the bedding and the alternation of beds of sandstone and shale have influenced the amount of open space resulting from the fracture of the rocks and have caused an irregular distribution of the ozokerite. The fissuring of the sandstone has produced more available open spaces than the fissuring of the clay and shale, and consequently the largest deposits of ozokerite are found in fissures in sandstone.

In addition to filling fissures, ozokerite occurs in the vicinity of zones of fracture as thin films along joint planes. These films imply that at the time of impregnation the ozokerite was fluid enough to penetrate very minute cracks, but the lack of impregnation of the country rock implies a viscosity too great to permit the penetration into rocks even as porous as sandstone.

The material removed from the mines and prospects is reported to contain from 1 to 7 per cent of ozokerite, but the quantity in a single prospect varies greatly within short distances.

¹ Taff, J. A., and Smith, C. D., *Ozokerite deposits in Utah*: U. S. Geol. Survey Bull. 285, p. 371, 1905.

² *Idem*, p. 360.

ORIGIN.

In this report, which is primarily economic, an exhaustive discussion of the probable origin of the ozokerite is hardly appropriate, but some of the considerations in regard to origin have an economic application.

There appears to be a close relationship between ozokerite and certain kinds of petroleum. In a paper by Gosling¹ an analysis of ozokerite is compared with one of American petroleum, and the comparison shows that the two substances contain the same compounds or fractions, though in different proportions. As would naturally be expected, the paraffin content of the ozokerite is higher than that of the petroleum. In the Galician mines all gradations between oil high in paraffin and ozokerite containing some petroleum have been observed.² Some of the veins of ozokerite in the Utah field have a width about equal to that of thick paper, a condition which implies a somewhat fluid state of the material at the time of impregnation and suggests that the substance which first filled the fissures was a petroleum rich in paraffin. Thus from laboratory and field observations all mixtures of petroleum and ozokerite are known to exist, and it may be concluded that the ozokerite of the Utah field is derived from a petroleum high in paraffin.

The passage from petroleum to ozokerite is thought by some geologists to have been accomplished by the oxidation and decomposition of the hydrocarbons of petroleum. However, the probability of the lack of oxidizing agents at considerable depths below the ground-water level would argue against this as a general process. On the other hand, it is now generally accepted that solid hydrocarbons, which of course embrace paraffin, exist in many crude oils at low temperatures. Kast and Seidner³ have found that the mud which separates out on the bottom of storage tanks containing crude petroleum is made up largely of paraffin, and they suggest that "this amorphous paraffin closely resembles and is evidently identical with ozokerite." Petroleum may be regarded as a solvent holding paraffin in solution, and on evaporation of the solvent the ozokerite is left as a residue. Slight changes in temperature, such as are found with increasing depth below the surface, would be a factor in solution and deposition, but this factor probably is not so important as evaporation of the lighter and more volatile oils of the petroleum.

The petroleum from which the ozokerite has been derived may have had two sources. It may have been derived from the overlying oil shale or it may have been forced up from lower beds. The

¹ Gosling, E. B., A treatise on ozokerite: *School of Mines Quart.*, vol. 16, p. 41, 1895.

² Redwood, Boverton, The Galician petroleum and ozokerite industries: *Soc. Chem. Industry Jour.*, vol. 11, p. 103, 1892.

³ Kast, H., and Seidner, S., The formation of solid paraffin: *Soc. Chem. Industry Jour.*, vol. 11, p. 598, 1892.

bituminous material in the oil shale is largely made up of vegetal remains, and it is thought by Peckham¹ that oil containing a large percentage of paraffin is indicative of a vegetable origin. On the other hand, Eldridge² believes that the veins of solid hydrocarbons in the Uinta Basin, to the northeast, were formed by the forcing into the crevices and later rapid solidification of semifluid hydrocarbons. It would be interesting to know if the ozokerite contains more volatile oils in the lower levels of the mines than in the higher, or if the reverse is true, as such facts may have a bearing on the source of the petroleum from which the ozokerite has been derived. Analyses of the ozokerite compared with analyses of oil from the oil shale might possibly show some significant resemblances.

Results of distillation tests on samples of oil shale collected by the writer in this region will be found in a paper in this volume entitled "Oil shale in northwestern Colorado and adjacent areas," by Dean E. Winchester.

COMPARISON WITH THE BORYSLAW FIELD IN GALICIA.

The ozokerite field of central Utah resembles in a number of places the Boryslaw field of Galicia, Austria, which is the most productive field of ozokerite. The Galician field, as described by Redwood,³ is less than 1 square mile in area. The ozokerite is found in fissures, usually measuring from 2 to 12 inches in width, which cut shale and sandstone of Miocene age that overlie beds of petroliferous shale. All gradations between solid ozokerite and petroleum rich in paraffin are found in the mines. A sample described by Redwood has a melting point of 60.5° C. and a specific gravity of 0.9236. The mine shafts in this field are very closely spaced and range in depth from 20 to 200 meters (66 to 656 feet). Much of the semifluid material is under high pressure, and it is reported that certain of the mine openings have at times been filled by the squeezing of semifluid ozokerite. The Boryslaw deposits become narrower with increasing depth, and Redwood is inclined to believe that the ozokerite has been forced up from below.

IMPORTS.

The figures given below, showing imports of ozokerite, are taken from the reports on the mineral resources of the United States, published by the Geological Survey. It is believed that the greater part of these imports came from the Galician mines, but the total production of the Galician field is probably considerably more than the amount given as imports to the United States.

¹ Redwood, Boverton, and Holloway, G. T., *Petroleum*, vol. 1, p. 233, 1896.

² Eldridge, G. H., *The Uintaite deposits of Utah: U. S. Geol. Survey Seventeenth Ann. Rept.*, pt. 1, p. 938, 1896.

³ Redwood, Boverton, *The Galician petroleum and ozokerite industries: Soc. Chem. Industry Jour.*, vol. 11, pp. 112-118, 1892.

Mineral wax (chiefly ozokerite) imported into the United States.

	Pounds.		Pounds.
1888.....	1, 164, 940	1912.....	6, 352, 003
1908.....	3, 595, 393	1913.....	7, 141, 514
1911.....	4, 472, 706	1914.....	8, 191, 529

The price at the point of exportation was 8.7 cents a pound in 1911, 7.7 cents a pound in 1912 and 1913, and 6.1 cents a pound in 1914.

PRODUCTION.

The first prospecting of this region was done in 1886. Since that time mining and prospecting have been carried on at irregular periods, for litigation has prevented continuous development. Exact figures for the production of the field are not available, and at the time of the writer's examination all the mines were inactive. According to statistics published by the United States Geological Survey in the yearly reports on mineral resources, the Utah field produced over 640,000 pounds of ozokerite previous to 1900, and it is reported by officials of the American Ozokerite Co. that the field has yielded about 120,000 pounds since that date. The total output of the Utah field is only a small fraction of the quantity imported into the United States in a single year, but the production of the past is not a measure of the production that is possible under favorable market and mining conditions.

CONCENTRATION.

The following concise description of the methods of concentration used in the Utah field is given by Taff and Smith:¹

The manner of separating ozokerite from the associated rocks is a simple process. The plant * * * consists of a steam boiler and engine, a crusher, and steam-heated vats. The soft rock and ozokerite mixture is crushed and run into long vats with narrow bottoms containing water kept at a boiling temperature. The ozokerite melts at a temperature of 54° to 70° C. (129° to 158° F.) and floats off as a liquid into cooling vats, while the rock is driven out along the narrow bottom of the vats by revolving screws. On cooling the ozokerite is remelted into dry pans to remove the moisture.

USES OF OZOKERITE.

Ozokerite is a nonconductor of electricity and is extensively used for insulating. Candles made from ozokerite have qualities superior to those found in other candles. Much of the ozokerite mined is converted into ceresin, a highly purified product which is used to replace or adulterate beeswax and has a variety of other uses. Ozokerite is also used as a foundation for various waxes and polishes; as a covering to protect metal surfaces from the action of moisture, acids, or alkalies; and for wax figures and dolls.

¹ Taff, J. A., and Smith, C. D., op. cit., p. 371.

MINES AND PROSPECTS.

In the following description of the mines and prospects, reference will be made to the map (Pl. I), on which the places where ozokerite deposits have been exploited are indicated and numbered. In the report by Taff and Smith¹ many of these localities are described in detail, and in the following description the data collected by them have been used to supplement the data collected by the writer. At the time of the field examination none of the mines or prospects described below were being worked commercially.

The westernmost development in the ozokerite field (No. 1, Pl. I) is in the E. $\frac{1}{4}$ sec. 20, T. 10 S., R. 7 E., and is locally known as the Culmer Bros. mine. A slope about 160 feet long has been opened, trending N. 10° W. at an inclination of 23° to 40° from the horizontal. About 100 feet below the mouth of the slope a main entry has been driven about 215 feet N. 11° $13'$ W. A few short side entries have been turned off from the slope as well as from the main entry. Two houses stand near the mine, and some hoisting machinery has been installed at the mouth of the slope. The most prominent fissures containing ozokerite trend N. 10° – 30° W. At the time of the examination the mouth of the slope was filled with loose material that had caved from the roof, rendering entrance impracticable. According to Taff and Smith,² the fracture zone is 2 feet 6 inches wide. It is reported that some large pieces of ozokerite have been taken from the slope and also that some yellow wax has been found here, but in the examination of the mine only thin films of soft ozokerite associated with gypsum were observed in the entry. A sample from this mine was tested as reported on pages 5–8.

Development No. 2, in the NE. $\frac{1}{4}$ sec. 21, T. 10 S., R. 7 E., consists of a shaft and a few open-cut prospects and is locally known as the U. S. property. This mine is equipped with electric hoisting machinery and a plant for the separation of the ozokerite from the associated rock fragments. At the time of the field examination the shaft was filled with water, so that entrance was impracticable. Mr. Vorhees, of Soldier Summit, reports that the shaft is 100 feet deep and that entries as long as 40 feet have been driven from the bottom of the shaft. Taff and Smith² state that the fractured rocks are 45 feet wide and the fissures have a trend of N. 60° W. In a prospect near the mouth of the shaft the ozokerite, which is well exposed, is irregularly distributed as a filling of the fissures, with a maximum width of 1 inch of solid wax. Along these fissures movement has taken place. The faults, which are normal, dip 45° and strike N. 45° W. The displacement is at least 18 inches, and the fracture zone is between 4 and 5 feet wide. The ozokerite from this prospect has a

¹ Taff, J. A., and Smith, C. D., *op. cit.*, pp. 369–372.

² *Idem*, p. 371.

more or less fibrous structure, is dark brown to black, and has a hardness about equal to that of talc.

Development No. 3, in the NW. $\frac{1}{4}$ sec. 22, T. 10 S., R. 7 W., consists of a drift about 500 feet long, bearing about N. 10° W. No ozokerite was observed on the mine dump, and only a few films were found filling joints that trend N. 10° W. It is reported that very little ozokerite has been found here. A sample from this place was tested at the Bureau of Mines. (See pp. 5-8.)

Development No. 4, in the E. $\frac{1}{4}$ sec. 24, T. 10 S., R. 7 E., consists of a drift about 30 feet long, opened along the principal joints, which here trend N. 8° W. This prospect is about 700 feet higher than the railroad station at Soldier Summit, as determined by barometric readings. A vein of ozokerite half an inch thick was observed in the face of the drift, but so far as could be observed this was the only vein in the prospect.

Development No. 5, in the SW. $\frac{1}{4}$ sec. 19, T. 10 S., R. 8 E., consists of a drift about 30 feet long, trending S. 85° E. The exposed system of joints trends N. 43° W. The drift is partly timbered and is equipped with a small car and track. No ozokerite was observed either in the mine or on the dump.

Development No. 6, locally known as the Soldier Summit mine, in the NW. $\frac{1}{4}$ sec. 30, T. 10 S., R. 8 E., less than half a mile northeast of Soldier Summit, is reported to be one of the largest mines in the field. Tests of a sample from this mine are reported on pages 5-8. The shaft was in so poor a condition at the time of examination that entrance was not feasible. The following description is taken from the report by Taff and Smith:¹

A mine has been equipped with hoisting power and in connection with it a concentration plant erected nearly one-third of a mile east of Soldier Summit. The mine was closed at the time visited, on account of reported litigation. Mr. Kroupa, who directed the development here, reports that the shaft is 225 feet in depth and was driven on a band of vertical fissures that contain the mineral wax, and that drifts had been opened 50 feet to the north and south on the strike of the fractures. A north-south shear zone has been prospected one-fourth mile south of the mine. In all cases here the ozokerite is reported to occur in veinlets filling narrow fissures in the strike of the crushed strata and surrounding the brecciated shale and shaly sandstone. Locally the veins swell to a thickness of nearly 3 feet, according to Mr. Kroupa's verbal report.

The mouth of the shaft has an altitude of about 400 feet above the railroad station at Soldier Summit.

Development No. 7, in the SW. $\frac{1}{4}$ sec. 10, T. 11 S., R. 8 E., consists of a shaft which at the time of visit was filled with water within about 20 feet of the surface. The ozokerite occurs in a brecciated zone that trends about N. 8° W. Evidences of ozokerite were found in the mine dump and in outcrops near the mouth of the shaft.

¹ Op. cit., p. 371.

Development No. 8, in the SE. $\frac{1}{4}$ sec. 10, T. 11 S., R. 8 E., consists of a small drift opened along the joints that have a trend of N. 9° W. Thin films of ozokerite associated with gypsum were seen. According to Mr. James Miller, of Colton, a number of small prospects similar to No. 8 have been opened northwest of this drift.

Development No. 9, in the SE. $\frac{1}{4}$ sec. 15, T. 11 S., R. 8 E., consists of a small drift and shaft opened along a normal fault in sandstone and clay. The rocks show a vertical displacement of about 8 feet and are brecciated along the fault zone. The ozokerite is confined for the most part to fissures in the brecciated portions of the sandstone and occurs in pockets or irregular masses. The clay carries little ozokerite, for even where it is faulted very little open space remains. A wagon road, which was in poor condition at the time of the examination, has been constructed from the Pleasant Valley mines to this prospect. According to barometric readings the mouth of the drift is about 650 feet higher than the town of Colton.

Development No. 10, in the SW. $\frac{1}{4}$ sec. 14, T. 11 S., R. 8 E., consists of a drift about 100 feet long driven along the principal joints, which here trend N. 10° W. This drift is about 475 feet above the town of Colton. The associated rocks are sandstone and shale, and masses of ozokerite were observed which measured as much as 6 inches across. The fracture zone in this drift is from 4 to 5 feet wide. The impregnated material exposed in the face of the drift is from 4 to 5 feet wide. The impregnated material exposed in the face of the drift was estimated by Mr. L. V. Shearer, of the American Ozokerite Co., to contain about 7 per cent of ozokerite. Tests of a sample of ozokerite from this mine were made as reported on pages 5-8. Angular fragments of country rock completely surrounded by ozokerite are abundant, and the smaller cross fractures are also filled with ozokerite in many places. The ozokerite from this drift is soft enough to be molded in the fingers. It has a more or less fibrous fracture and on freshly broken surfaces smells like kerosene.

Development No. 11, in the SW. $\frac{1}{4}$ sec. 14, T. 11 S., R. 8 E., consists of a drift about 200 feet long and some small crosscuts. The drift is opened along the principal system of joints and trends N. 10° W. The general level of this drift is about 400 feet above the town of Colton. Ozokerite is found in films and thin veins along the principal joints and also in the smaller joints that cut the major system. It is probably a part of the same impregnated body that is found in development No. 10. Nos. 9, 10, and 11 are locally known as the Brown Bear group or James Peak group.

Development No. 12, in the SE. $\frac{1}{4}$ sec. 22, T. 11 S., R. 8 E., in the town of Colton, is locally known as the Town mine. At the time of

the examination the mine was partly filled with water. The following description of this development is given by Taff and Smith:¹

A shaft is sunk on a vertical shear zone 5 to 6 feet in width to a depth of 110 feet and is equipped with a 10-horsepower hoisting engine. Drifts have been run on the strike of the fractures at a depth of 45 feet and at the base. The mine is now closed, it is claimed, on account of litigation. At the time of inspection it was filled with water below the 45-foot drift. At this level the brecciated zone consists of broken green and purple shale with sandstone fragments. Ozokerite occurs in scales or thin veins or as pockets and veins of variable extent and width, not exceeding a few inches at most.

Development No. 13 is in the NE. $\frac{1}{4}$ sec. 23, T. 11 S., R. 8 E., on what is locally known as the Midnight claim. A drift has been opened here, principally in sandstone, along the brecciated fault zone, which is between 2 and 3 feet wide, and has a north-south trend. Ozokerite was observed at the surface in solid masses as thick as $1\frac{1}{4}$ inches and filling smaller fissures and spaces between the faulted and brecciated rocks.

Development No. 14, locally known as the Miller property, is in the SE. $\frac{1}{4}$ sec. 14, T. 11 S., R. 8 E., and consists of two drifts, one 75 feet long and the other 17 feet long. The shorter drift is about 12 feet above the long one. It is reported that about 5 tons of material has been mined from these drifts and that some of it contained as much as 7 per cent of ozokerite.

Development No. 15, locally known as the Pleasant Valley or P. V. mine, is probably the largest and best-equipped mine in the ozokerite field. Two main drifts have been opened, one in the NW. $\frac{1}{4}$ sec. 24 and the other in the SW. $\frac{1}{4}$ sec. 13, T. 11 S., R. 8 E., and are connected by a shaft. The lower drift is about 300 feet above the town of Colton, and the other is about 85 feet higher. Both drifts have been driven on a fracture zone which has a general bearing of N. 10° W., but the trend of the drifts ranges between N. $0^{\circ} 58'$ W. and N. 15° W. The lower drift is about 650 feet long, and the upper about 350 feet, and some lateral entries have been turned off which are over 100 feet long. The two levels are connected in several places, and it is reported that the lateral entries show that the fracture zone containing ozokerite is locally 38 feet wide. Single continuous veins of ozokerite have been traced in these mines for 140 feet, and yellow wax has been found in the upper drift. The main part of the lower drift is opened along a normal fault, which is nearly vertical and has a displacement of over 6 feet. The associated rocks are sandstone, shale, and clay, and these commonly show slickensided surfaces. A plant for the separation of the ozokerite from the associated rock fragments, several houses, and a shop have been erected. It is reported by Mr. L. V. Shearer that shipments of wax were made from this mine to New York City in 1901, 1907, and 1912, which aggregated between 35 and 50 tons. Tests of a sample from the mine were made at the Bureau of Mines, as reported on pages 5-8.

¹ Op. cit., pp. 370-371.

Development No. 16, locally known as the Higgins shaft, is in the NW. $\frac{1}{4}$ sec. 24, T. 11 S., R. 8 E. The shaft is reported to be about 180 feet deep but at the time of examination was in so poor a condition that entrance was not practicable. It is probable that this shaft is on the same general zone of fractures as the P. V. mine. A sample from the mine was tested, as reported on pages 5-8. About 600 feet south-southeast of the shaft is an old prospect, which shows traces of ozokerite on the dump.

Development No. 17, locally known as the Kyune Canyon property, is in the SE. $\frac{1}{4}$ sec. 18, T. 11 S., R. 9 E. It consists of a drift over 100 feet long. The general direction of the fractures which carry the ozokerite is N. 5° E., and exposures in the drift show ozokerite in small fissures as much as half an inch thick, scattered through a zone several feet thick.

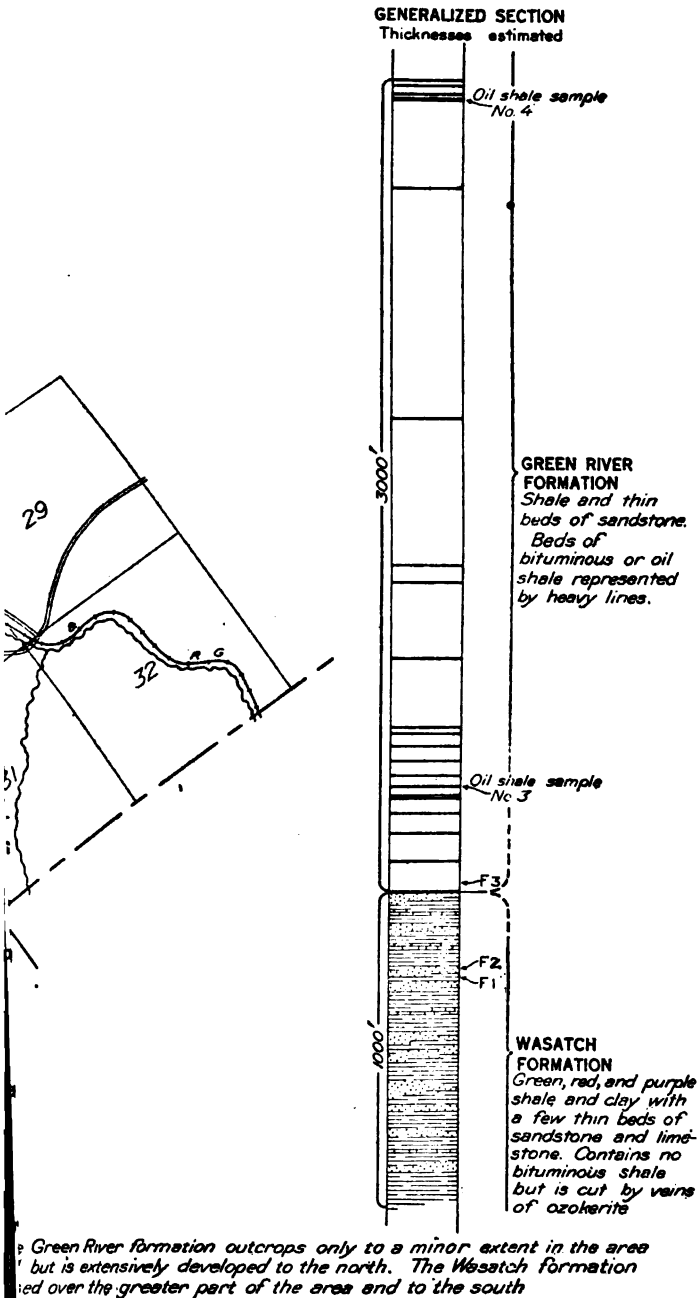
In the descriptions given above only those developments have been considered which show some indication of ozokerite or which have apparently been opened with the intention of commercial development. A number of small prospects were visited, and other occurrences were reported in various parts of the ozokerite field.

FUTURE OF THE FIELD.

The quantity of ozokerite available for future mining in the Utah field can hardly be estimated. The length and thickness of the fissured and fractured zones containing ozokerite are variable, even within short distances, and for areas beyond the limits of prospected ground no quantitative estimate can be made with safety. Many of the prospects and mines, however, showed ozokerite in place, and the fact that it is irregularly distributed should encourage more thorough prospecting.

The melting point of crude Utah ozokerite ranges between 60° and 79° C., which compares favorably with that of the Austrian product. Inasmuch as the melting point is a factor in determining the price, the quality of the Utah product, so far as this point is concerned should encourage future development.

Previous to the outbreak of the war in Europe the Austrian ozokerite sold in New York at so low a price that American producers found difficulty in competing with it. For the year 1914 the imported ozokerite was valued at 6.1 cents a pound at the point of exportation, and in the summer of that year the New York price for crude ozokerite was 27 to 30 cents a pound. About the middle of June, 1915, the price of ozokerite in New York, as shown by the various trade journals, was between 30 and 40 cents a pound. As the imports from the Galician mines have been seriously affected by the war and as the development of these mines in the near future will probably be greatly handicapped, there is an excellent opportunity to market the Utah product.



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DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 641—B

THE OIL AND GAS GEOLOGY OF THE
FORAKER QUADRANGLE
OSAGE COUNTY, OKLAHOMA

BY

K. C. HEALD

Contributions to economic geology, 1916, Part II

(Pages 17-47)

Published August 21, 1916



WASHINGTON

GOVERNMENT PRINTING OFFICE

1916

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THE OIL AND GAS GEOLOGY OF THE FORAKER QUADRANGLE, OSAGE COUNTY, OKLAHOMA.

By K. C. HEALD.

INTRODUCTION.

Scope of paper.—The aim of this paper is to describe and portray those features of the Foraker quadrangle which may be of interest and assistance in the discovery and development of accumulations of oil and gas. In the first part of the paper the character of the surface and the accessibility of different parts of the quadrangle are discussed. Under the heading "Stratigraphy" those strata which are valuable as key horizons in mapping structure are described in detail, and the probable positions of oil sands are given. Under the heading "Structure" the geologic structure is portrayed by map and stereogram, and the anticlines which the writer believes favorable for the accumulation of oil and gas are described in detail. In conclusion specific recommendations for prospecting are given, and the writer's belief concerning the probability of the occurrence of oil and gas accumulations is set forth.

Location.—The Foraker quadrangle lies in the extreme northwest corner of Osage County, Okla., between meridians $96^{\circ} 31'$ and $96^{\circ} 45'$ and parallels $36^{\circ} 45'$ and 37° . Its north boundary is just north of the Kansas-Oklahoma line. (See fig. 1 and Pl. II.)

Field work.—The field work that furnished the data for this report was done during the summer and fall of 1915. Headquarters were made in the towns of Grainola and Foraker, where good hotel accommodations were obtained, and in Foraker very good livery service was available. Reconnaissance trips were first made over the area, after which the detailed work necessary for mapping the geology was done. Several recognizable beds of limestone were traced through the region, and elevations were taken at many points along the outcrops. These elevations were obtained by plane-table work, supplemented by a few hand-level observations close to established bench marks. The work was much facilitated by the excellent base map prepared by the Geological Survey in 1914, on which the surface

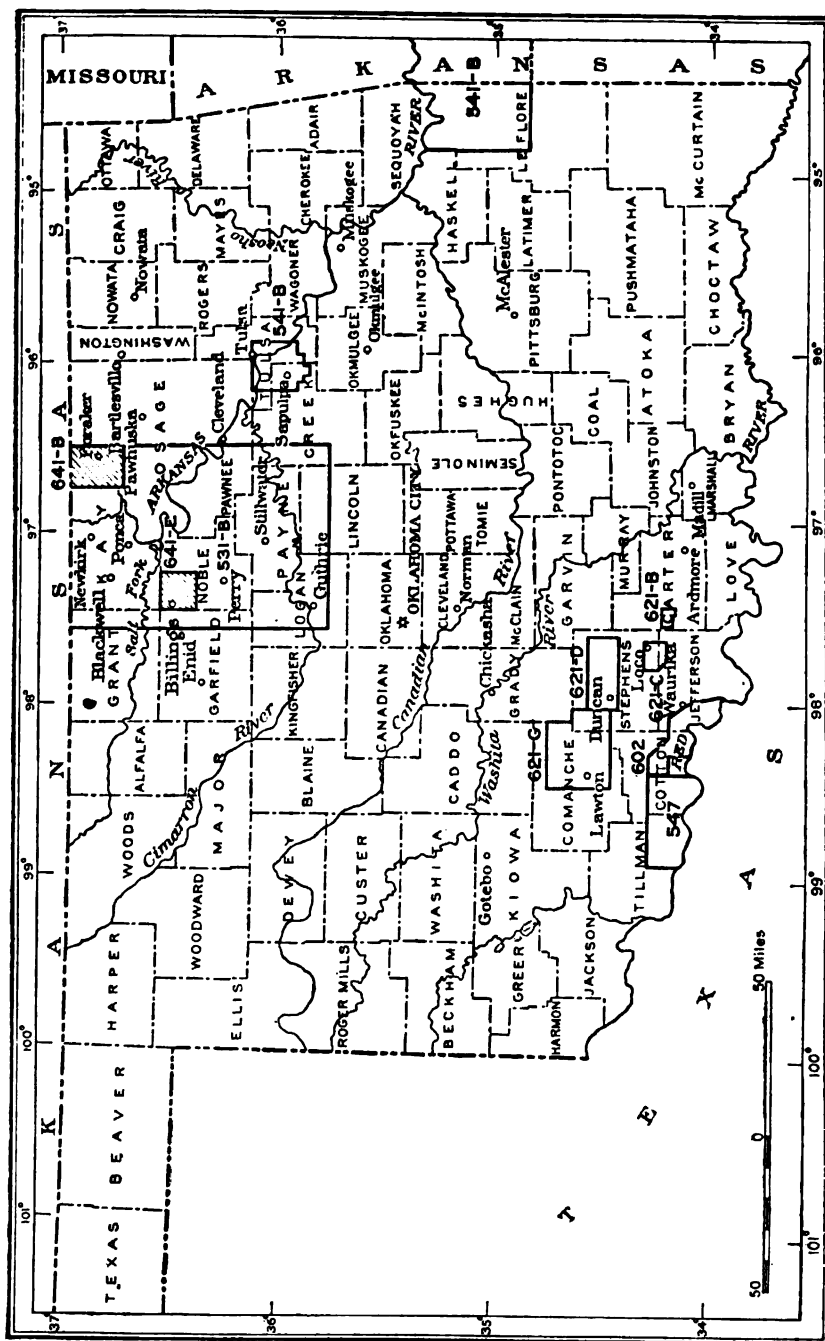


FIGURE 1.—Index map of Oklahoma showing location of Foraker quadrangle (marked "641-B"). The districts indicated by heavy lines have been described in separate papers, the number of which appear in black type.

features are represented by contour lines with a 20-foot interval. (See Pl. II.) Bench marks are established at most of the section corners and quarter corners.

GEOGRAPHY.

Relief.—A view westward from the rim of the scarp west of North Bird Creek, near the east side of the Foraker quadrangle, gives the general impression of a great plain with almost no relief. This plain seems to slope gently for some 15 miles to the steep bluffs west of Beaver Creek, which are the southern extension of the Flint Hills of Kansas. In places there are scars, which evidently mark steep-sided valleys, and a few low hills modify the regularity of the surface, but they are not prominent. This smooth-appearing plain, however, is cut by numerous valleys. Erosion is active, and gulches and valleys are being vigorously excavated. The resultant *débris* is carried away by the streams before it has a chance to accumulate in any great quantity, and consequently the valley sides are steep, although the many beds of soft shale

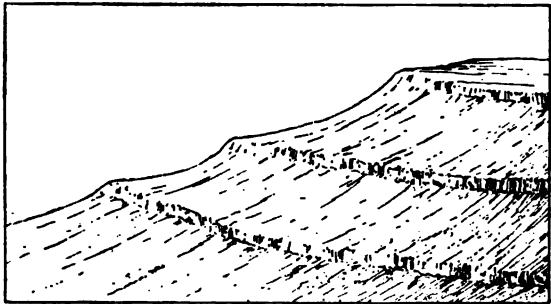


FIGURE 2.—Hill slope showing alternating hard and soft strata.

prevent the development of prominent cliff faces. The more resistant rocks form conspicuous outcrops, whereas the softer, less resistant shales and thin limestones are carried away faster, and because of this difference the resultant slope has the appearance of a series of steps or terraces, such as are shown in figure 2.

The most striking topographic features in the quadrangle are the bluffs west of Beaver Creek, in the northwest corner, and those which rim the valleys of Buck Creek, Sand Creek, North Bird and Middle Bird creeks, at the eastern margin. These scarps show the same general feature of alternating gentle and steep slopes as is shown in the valley sides, except that the slope, taken as a whole, is more abrupt—in fact, the scarps are so abrupt and so continuous that they form considerable obstacles to travel by vehicle. Both lines of bluffs vary locally in trend, having reentrants and projections in response to the locations of stream courses and consequent erosional activity, but they maintain a constant general direction of a little east of north.

Drainage and water supply.—Most of the Foraker quadrangle is drained by Salt Creek, which heads a little south of the Kansas line and flows southward through the center of the area. About 30 square miles in the northwest corner is drained by Beaver Creek, and the water from a narrow strip along the east edge flows into the headwaters of Buck Creek, Sand Creek, North Bird and Middle Bird creeks, which are pushing west and encroaching on the Salt Creek drainage basin.

In years of slight rainfall all the streams are intermittent and a large percentage of the wells in the quadrangle go dry. The water in the wells comes from joint planes in limestone, as is clearly indicated by several shallow wells that give an abundance of water, though comparatively deep wells near by are dry. For this reason it is suggested that drilling for water should not go to a depth exceeding 75 feet, not only because the cost of drilling increases with increasing depth, but because joint planes are presumably more abundant near the surface. All the water in the area is limy and would doubtless leave quantities of scale in boilers.

Culture.—The Foraker quadrangle is traversed by but one railroad, the Midland Valley, whose trains stop at Foraker, Grainola, and Frankfort. Foraker and Grainola are small towns, the only ones in the quadrangle, and Frankfort is a flag station. The southwestern part of the district can be more easily reached from the town of Burbank, on the Santa Fe Railway, only 4 miles south of the southwest corner of the quadrangle.

The greater part of the land is given over to the cattle industry, which is in a very thriving condition. Agriculture is not neglected, however, and there are few places in the quadrangle that are more than a mile from cultivated land.

The road net is very good, although the roads themselves are not. A large percentage of the section lines are open, and in dry seasons practically any of them may be traveled with a team, or even with an automobile. Good roads could be made along any of them with comparatively little expense. The many limestone outcrops could furnish an abundance of excellent road metal for use in places that are inclined to be soft in rainy weather, and slight detours from section lines would do away with the necessity of grading any bad hills. The most troublesome feature is the lack of bridges over the larger streams, which during very rainy weather may be impassable for several days at a time. The only good wagon bridge in the quadrangle is the one over Elm Creek, $2\frac{1}{2}$ miles west of Foraker. This is a very serviceable bridge, built of rock quarried at the bridge site. More work of this nature would go far toward making travel throughout the quadrangle possible in any weather.

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STRATIGRAPHY.**ROCKS EXPOSED.****AGE AND GENERAL CHARACTER.**

The stratigraphic column in the Foraker quadrangle is made up of rocks of lower Permian and upper Pennsylvanian age.

The exposed rocks are all sedimentary. Limestone and shale are the most abundant, but some sandstone is present. The conspicuous outcrops of the limestone beds and the control they exert over the surface features make them much the most important rocks of the section when structural mapping is attempted, because they can be easily traced. By means of elevations taken on these beds the position and slope of the strata may be determined.

No complete description of the stratigraphy will be given in this paper, but for the convenience of those who wish to do detailed geologic work in this region the most prominent beds or key rocks are described in detail below. The general relations of the beds are shown in figure 3.

KEY ROCKS.

Wreford limestone.—The Wreford limestone is from 10 to 14 feet thick in the Foraker quadrangle. It occurs in three distinct layers. Between the middle and bottom layers there may be a bed of shale,

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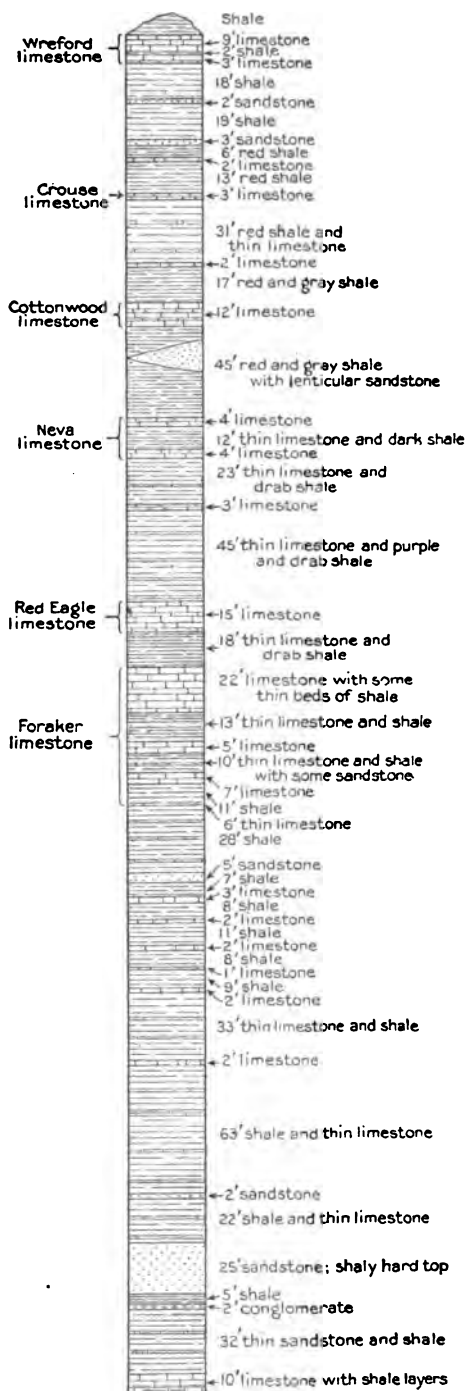


FIGURE 3.—Stratigraphic section of rocks exposed in the Foraker quadrangle, Okla.

which has a thickness of 2 feet at the locality where it appeared best developed.

The distinguishing features of the Wreford are the buff color of the middle bed and the character and mode of occurrence of the chert which forms a large part of the rock. The chert, owing to its greater hardness than the limestone in which it is embedded, weathers into all manner of irregular projecting lumps and knobs. At some localities imperfectly silicified limestone takes the place of the chert and projects from the body of the rock in prominent layers, large pieces of which litter the ground in the neighborhood of the outcrop.

The character of the formation is shown in detail in the following section :

Section of Wreford limestone half a mile east of Hardy, Okla.

	Feet.
Limestone, blackish gray on weathered surface, light buff to brownish gray on fresh surface; in several slabby beds 2 to 6 inches thick; top bed is massive, 12 to 16 inches thick, hard and dense; lower beds break into slabby, lenticular pieces. Fossiliferous; considerably limonitized; has many echinoid spines; is in places full of smooth cylindrical holes half an inch to 3 inches in diameter. Above this is a mass of shale and limestone-----	4
Limestone, buff, hard, dense, massive; full of chert; yellowish brown on weathered surface, blue-gray on fresh surface. About 25 per cent of the rock is chert, in irregular nodules and layers, lens-shaped concretions roughly parallel to bedding most common; chert is fossiliferous-----	3
Shale, limy, yellow-gray to green-gray; looks sandy but no grains distinguishable; bedding regular; fossiliferous-----	2
Limestone, light buff on both weathered and fresh surfaces, dense, hard, compact; full of fossils, which are locally replaced by glassy or milk-white calcite; in two beds with a 1-inch shale parting; the many crystalline fossils give the rock a spotted appearance-----	3
	12

Crouse limestone.—A prominent limestone about 3 feet thick, the Crouse, lies approximately 70 feet below the base of the Wreford. Its outcrop is almost invariably conspicuous, and the rock is distinctive enough to make it easily recognizable. The characteristic features of this limestone are the form of the outcrop, which shows many large, massive blocks, the absence of recognizable fossils in any abundance, with the exception of small *Fusulinas*, which are plentiful, and the presence of many smooth, round holes that are vertical or steeply inclined to the bedding. There are similar holes in other limestones of this region, but nowhere were they noted in such numbers as in the Crouse limestone.

Cottonwood limestone.—The Cottonwood limestone is from 10 to 16 feet thick in the Foraker quadrangle. It is thickest near the

Kansas line and thins to the south. Of the total thickness usually only the top 2 feet is visible, the remainder being covered with soil. This is due to the fact that the top 2 feet consists of hard, resistant limestone, while the remainder of the formation is made up of thin oolitic limestone and shale. In some localities there is a thin limestone conglomerate at the base of the formation. Although the thin limestones at the base do not form prominent outcrops, they are the most easily recognizable feature about the formation, because of their lithologic character and the fact that they carry many fossils, among which a small coiled shell (*Schizostoma*) is common. This coiled shell was rarely observed at any other horizon. In this quadrangle a thin oolitic limestone, with an abundance of fossils, especially *Schizostoma*, is almost certain to be at the base of the cottonwood limestone.

The following section measured north of Grainola gives a detailed description of the formation:

Section of Cottonwood limestone in the SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 21, T. 29 N., R. 6 E.

	Ft. in.	
Massive limestone, bluish white on weathered surface, light gray to light buff on fresh surface; surface uneven and full of round holes as much as 2 inches in diameter, but it is not as rough as the Neva (see below); occasional rough pieces have dark surfaces; no chert-----	2+	
Thin shale and oolitic limestone-----	11	0
Limestone conglomerate, blue-gray to yellowish; made up of rolled pebbles of limestone, shell fragments, and some little hematite pebbles; degree of cementation varies; a good deal of crystalline calcite; many fossils; coiled shells (<i>Schizostoma</i>) and fluted, long-nosed brachiopods (<i>Meekella</i>) most characteristic-----	6	
Shale, olive-drab, clayey-----	2	0
Limestone conglomerate as above, except that it contains more pebbles and less lime; fossiliferous (<i>Myalina</i> , <i>productids</i>); cross-bedded; largest pebbles seen about half an inch in diameter-----	2	0
Shale or marl, pink, greenish gray, and white; bedding irregular; beds form overlapping lenses; contact with overlying conglomerate very irregular-----	2	6
	20+	

Neva limestone.—The Neva limestone furnishes one of the most prominent outcrops in the Foraker quadrangle. It is easily distinguished from any of the limestones occurring higher in the section, and also from those lower in the section, with the exception of the Red Eagle limestone, which lies about 55 feet below the Neva. The total thickness of this formation is 15 to 20 feet. It is made up of massive beds, 4 to 6 feet thick, at the top and the base, with thin beds of limestone and shale between. The total thickness of the top bed

is rarely seen, as the rock is evidently very soluble. The float is covered with jagged points and pinnacles which are so sharp and numerous that it is painful to handle a piece. A fresh fracture discloses numerous irregular cavities which may be filled with light-colored incoherent granular material.

In many places the weathered surface of the lower bed is very rough, but it does not reach the degree of irregularity that is shown by the upper bed. The cavities in the lower bed are usually lined with bright-brown limonite. Both of the massive beds are fossiliferous, but the thin beds between them are much more so. These thin beds also carry much chert. In many localities a very persistent cherty bed is found about 2 feet above the lower massive bed.

Red Eagle limestone.—The Red Eagle limestone is so named because of its excellent exposures near the Red Eagle School, southwest of Foraker. Its total thickness was not surely determined; in some places it is at least 17 feet, but in others it is probably much less. The Red Eagle consists of a number of distinct beds of limestone, between which are beds of shale in some localities. One of the most distinctive features of the top bed of the limestone in much of the quadrangle is the character of the fresh surface, which shows an abundance of tiny grains of crystalline calcite, giving the surface the appearance of having been covered with frost or light snow. The following section gives the details of the upper part of the limestone in the southwestern part of the quadrangle. At this locality there are no shale partings, but the limestone varies in character. The thickness of the several members is estimated.

Section of Red Eagle limestone on tributary of Hay Creek, a quarter of a mile east of corner of secs. 1, 2, 11, and 12, T. 26 N., R. 5 E.

	Ft.	in.
Limestone, gray, thin bedded, slabby, clayey-----	3	9
Limestone, creamy buff on weathered surface, medium hard; breaks easily but is not glassy brittle; fossiliferous; lower part of bed has much limonite-----	1	0
Limestone, thin bedded, blocky rather than slabby, light gray, brittle, hard, fossiliferous-----	4	0
Limestone, dove-gray on fresh surface, massive, clean, hard, brittle, fossiliferous; good bed to burn-----	1	6
Limestone, dove-gray, pure; makes persistent bed but weathers back under overlying bed-----		3
Limestone, thin bedded, rough, slabby, whitish gray on weathered surface, blue-gray on fresh surface; in part good limestone, in part rather clayey; fossiliferous (corals, productids)-----	4	0
Limestone, pigeon-blue on weathered surface, brownish gray on fresh surface, much limonitized; does not weather rough; fossiliferous; medium hard-----	2	0

16 6

In tracing this limestone for the purpose of determining structural conditions great care must be exercised, as it is easy to mistake the outcrop of one bed for that of another and so introduce an error. A mistake of small actual amount may be relatively great in its effect because of the low dips prevalent in this region.

Foraker limestone.—The Foraker limestone, which forms the rim of Ekler Canyon and is prominent along the line of bluffs in the eastern part of the quadrangle, is about 74 feet thick. Although the great part of this thickness is made up of limestone, much of the rock is so soft and thin bedded as to give no outcrop. Some soft shale is also present. The heavy limestone may be easily recognized by the large number of *Fusulinas* which it contains, the rock in places being fairly jammed with them. Another distinguishing mark is the great abundance of chert concretions which occur in this limestone. The fresh surface of the chert has in general a light blue-gray color, and the concretions usually include fossils which show white against the bluish background. The most common fossil in the chert is *Fusulina secalica* Say, but there are also small brachiopods and a few corals and crinoid stems.

Sandstone.—A sandstone, to which no name has been given, occurs about 28 feet below the base of the Foraker limestone. It is a particularly good horizon marker, as it is some distance either above or below other sandstones with which it might possibly be confused. Its lithologic character also makes its identification simple.

The average thickness of this bed is about 3 feet, though locally it is more, a thickness of 7 feet having been observed at one place. In some localities, however, this sandstone is probably absent—at least there is no trace of it on the surface.

The color of the weathered surface is reddish gray. The fresh surface is lighter in color and thickly dotted with small coffee-brown spots which are probably manganiferous. The most distinctive feature is the presence of muscovite. In many places this mineral is very prominent, and it can always be detected if the rock is examined carefully. The sand making up the body of the rock is extremely fine grained translucent quartz. Many of the grains are but slightly rounded, crystal faces with clean, sharp corners being present in abundance. This feature may be observed without the help of a lens, as the sunlight is reflected from many tiny flashing points on a fresh surface of the rock. In places this sandstone is somewhat limy, but in most of the localities where it was tested no calcium carbonate was present.

ROCKS NOT EXPOSED.**IMPORTANCE.**

In order to predict with any degree of probability as to the occurrence of oil or gas at any particular locality, it is necessary to have a knowledge not only of the structure which may be detected by examination of the strata that crop out at the surface, but also of that shown by the strata that occur below the surface to any depth which may be reached by the drill. An anticline whose shape is favorable for the accumulation of oil and gas and which is surrounded by a plentiful gathering ground but which lacks the proper succession of strata to transport and retain the oil would be of as much value to the oil man as a dry creek bed would be to a man in search of water. Without the proper succession of pervious and impervious strata oil accumulation will seldom take place. On the other hand, a knowledge that such a succession of strata is probably present will make it desirable to explore many localities where, if such knowledge were lacking, the chance of finding oil would not be considered good enough to justify the expense of drilling.

The deepest of the sands which probably underlie this field and which have been proved to contain oil at adjacent localities is that known as the Tucker or Meadows sand. Although it is possible that there are oil-bearing sands below this one, it has never been proved for north-central Oklahoma, and only the strata lying between the Tucker sand and the surface will be considered in this paper.

SOURCES OF INFORMATION.

Knowledge of the strata which underlie any given locality may be obtained in two ways. The first is by actual observation of the strata where they rise to the surface at some distance from the locality concerning which information is desired. In comparatively few places do the strata maintain a horizontal position for any great distance. More commonly they are tilted to a greater or less degree, and where this is the case it is only necessary to travel in a direction opposite to that toward which they are tilted to reach the outcrop of any persistent bed. This is particularly true of a region where the strata uniformly dip in one direction, as in northeastern Oklahoma. The difficulty encountered where the beds have been only slightly tilted is the great distance that must be traversed before a bed which lies at any considerable depth will be found at the surface. Even when the point of outcrop is attained, it may be found that the soil is so thick that nothing can be learned of the character of the rocks which lie below. In northeastern Oklahoma, where the average dip to the west is only about 30 feet to the mile, it would be necessary

in order to measure a section having a vertical extent of 3,000 feet, to determine the character and thickness of the beds outcropping over a distance of about 100 miles. It is therefore evidently impracticable if not impossible to obtain in this way accurate knowledge of the strata which lie below the surface.

The second source of information is that furnished by the records of the strata passed through when wells are drilled. All such records are valuable and should be preserved. A good well record furnishes more accurate information concerning the succession of the strata below the surface than can be obtained in any other way, and by the study and comparison of such records it is possible for a geologist to determine the changes that occur in the thickness and character of the strata, and under some conditions to tell with precision what succession of beds will be encountered in regions which have not been explored by the drill but which are not far removed from those that have been.

No wells have been drilled in the Foraker quadrangle, but several have been sunk at points not very far distant, and the logs of these wells, supplemented by surface data, permit tracing of the underground formations with small probability of error.

GENERAL CHARACTER AND AGE.

The strata between the surface and the Tucker sand are of Pennsylvanian age, with the exception of the uppermost beds in the northwest corner of the quadrangle, which include some of the Permian rocks that crop out farther east.

The upper thousand feet of the rocks below the surface are dominantly shale and, in slightly less total thickness, limestone. Lower down the limestones are of insignificant amount in comparison to the shale and sandstone. Most of the lower part of the section above the Tucker sand is occupied by shale, which may be blue, black, or brown, with scattered red bands. The nature of the formations encountered in a well drilled a short distance west of the quadrangle is shown in the log given on page 28.

Log of Mary Hess well No. 1, in sec. 4, T. 28 N., R. 4 E.

[By E. W. Marland and others.]

	Thick- ness.	Depth.		Thick- ness.	Depth.
	<i>Feet.</i>	<i>Feet.</i>		<i>Feet.</i>	<i>Feet.</i>
Soil.....	8	8	Lime.....	15	1,242
Lime.....	17	25	Shale.....	16	1,258
Shale.....	20	45	Lime.....	12	1,270
Red rock.....	5	50	Shale.....	10	1,280
Lime.....	20	70	Lime.....	23	1,303
Red rock.....	20	90	Shale.....	37	1,340
"Slate".....	20	110	Sand (water).....	80	1,420
Red rock.....	20	130	Shale.....	25	1,445
Lime (Wrexford limestone).....	20	150	Sand.....	77	1,475
Red rock.....	15	165	Shale.....	30	1,552
Shale.....	5	170	Lime.....	8	1,560
Red rock.....	20	190	Shale.....	5	1,565
Lime.....	5	195	Red rock, pink.....	5	1,570
Red rock.....	5	200	Sand and shale, cavy.....	20	1,580
Lime.....	20	220	Red rock.....	13	1,603
Red rock.....	10	230	Sand.....	5	1,608
Lime.....	5	235	Lime.....	4	1,612
Red rock.....	10	245	"Slate".....	48	1,660
Lime.....	5	250	Red rock.....	35	1,695
Shale.....	5	255	"Slate".....	10	1,705
Lime.....	10	265	Broken sand.....	30	1,735
Red rock.....	15	280	"Slate".....	95	1,830
Lime (Cottonwood limestone).....	20	300	Lime.....	5	1,835
Red rock.....	65	365	"Slate".....	20	1,855
Lime.....	30	395	Sand (water and gas).....	50	1,905
Shale.....	5	400	"Slate".....	6	1,911
"Slate".....	20	420	Red rock.....	10	1,921
Lime.....	5	425	"Slate".....	182	2,103
Lime.....	40	465	Sand.....	27	2,130
Lime slate (Foraker limestone).....	5	470	Sand.....	65	2,195
Lime.....	60	530	"Slate".....	12	2,207
"Slate".....	10	540	Lime.....	18	2,225
Lime.....	20	560	"Slate".....	130	2,355
Shale.....	15	575	Sand.....	12	2,367
Lime.....	10	585	Sand (water).....	38	2,405
Shale.....	45	630	Bottom sand.....	5	2,410
Lime.....	10	640	Lime and slate.....	10	2,420
"Slate".....	18	658	Sand.....	80	2,500
Lime.....	17	675	Red rock.....	30	2,530
"Slate".....	25	700	"Slate".....	35	2,565
Lime.....	10	710	Shale.....	60	2,625
"Slate".....	35	745	Sand and shale.....	15	2,640
Lime.....	10	755	Shale.....	70	2,710
Shale.....	22	777	Lime.....	6	2,716
Lime.....	3	780	Black shale.....	6	2,722
Shale.....	20	800	Lime.....	7	2,729
Lime.....	3	803	Shale.....	101	2,830
Shale.....	19	822	Lime.....	5	2,835
Lime.....	23	845	Shale.....	5	2,840
Shale.....	20	865	Sand.....	15	2,855
Lime.....	5	870	Black shale.....	28	2,883
Shale.....	5	875	Lime.....	52	2,935
Lime.....	40	915	Sand.....	8	2,943
Shale.....	25	940	Shale.....	5	2,948
Lime.....	10	950	Lime.....	22	2,970
Shale.....	20	976	Sand.....	24	2,994
Lime.....	8	984	Black shale.....	10	3,004
Shale.....	12	996	Sand.....	13	3,017
Lime.....	4	1,000	Coal.....	5	3,022
Shale.....	8	1,008	Sand.....	7	3,029
Lime.....	2	1,010	Black shale.....	48	3,077
Shale.....	10	1,020	"Slate".....	63	3,140
Lime.....	10	1,030	Sand.....	25	3,165
Shale.....	13	1,045	Gray sand (water).....	20	3,185
Sand.....	10	1,055	Shale.....	58	3,243
Shale.....	65	1,120	White lime.....	5	3,248
Lime.....	10	1,130	Black lime.....	18	3,266
Shale.....	15	1,145	Limy sand; plugged at 3,485 feet.....	219	3,485
Lime.....	75	1,220			
Shale.....	7	1,227			

CORRELATIONS.

The determination of the rocks underlying the surface of the Foraker quadrangle was much simplified by the work of the Oklahoma Geological Survey in identifying the Neva limestone, which crops out just west of the town of Cushing, and determining the relation of the Neva to the Pawhuska limestone, which crops out at Drumright, the Neva and Pawhuska limestones forming the top and base, respectively, of a measured stratigraphic section. This section shows that the top of the Pawhuska lies 552 feet below the base of the Neva limestone.¹ As the relation of the oil sands to the Pawhuska limestone in the Cushing field is known, their relation to the Neva is also determined. The Neva limestone crops out extensively in the Foraker quadrangle. There are differences between the succession of strata lying below it here and that in the Cushing field, dependent on the persistency of the individual beds, both as regards thickness and character, but the changes may be recognized by a study of the logs of the wells in the territory between the two areas.

The approximate horizons of the formations occurring at the mouths of holes drilled near Ralston, Blackburn, Fairfax, Ponca City, and Newkirk are known, and thus starting points were available for the comparison of each well record with others. In this way the formations occurring at Cushing were traced northward through Pawnee, Osage, and Kay counties, with small probability of error, and were recognized in wells that have been drilled only a few miles west of the Foraker quadrangle. From the proximity of these wells to the quadrangle it is inferred that the same succession of beds will be found here as in the localities where the wells were drilled.

As a result of the work described above, it may be confidently stated that below the surface of the Foraker quadrangle there are sands at the horizons of the main producing sands of the Cleveland and Cushing fields. In addition to these sands, which lie more than 2,000 feet below the surface, there are undoubtedly some of the higher sands which have been found to carry oil and gas in the western part of Kay County. If oil and gas are not found in the Foraker quadrangle, it will not be for lack of strata which are suitable to contain them.

The approximate distances between the top of the Foraker limestone and the sands corresponding to those of the Cleveland pool are as follows: Foraker limestone to Layton sand, 1,680 feet; to Cleveland sand, 1,940 feet; to Wheeler sand, 2,420 feet; to Bartlesville sand, 2,850 feet. So far as could be determined there is no break between the

¹ Buttram, Frank, The Cushing oil and gas field, Okla.: Oklahoma Geol. Survey Bull. 118, pp. 9-10, 1914.

Bartlesville and Tucker sands in this region. The relations of the sands found at Cushing to those found west of the Foraker quadrangle and a little south of the Kansas line are shown in figure 4.

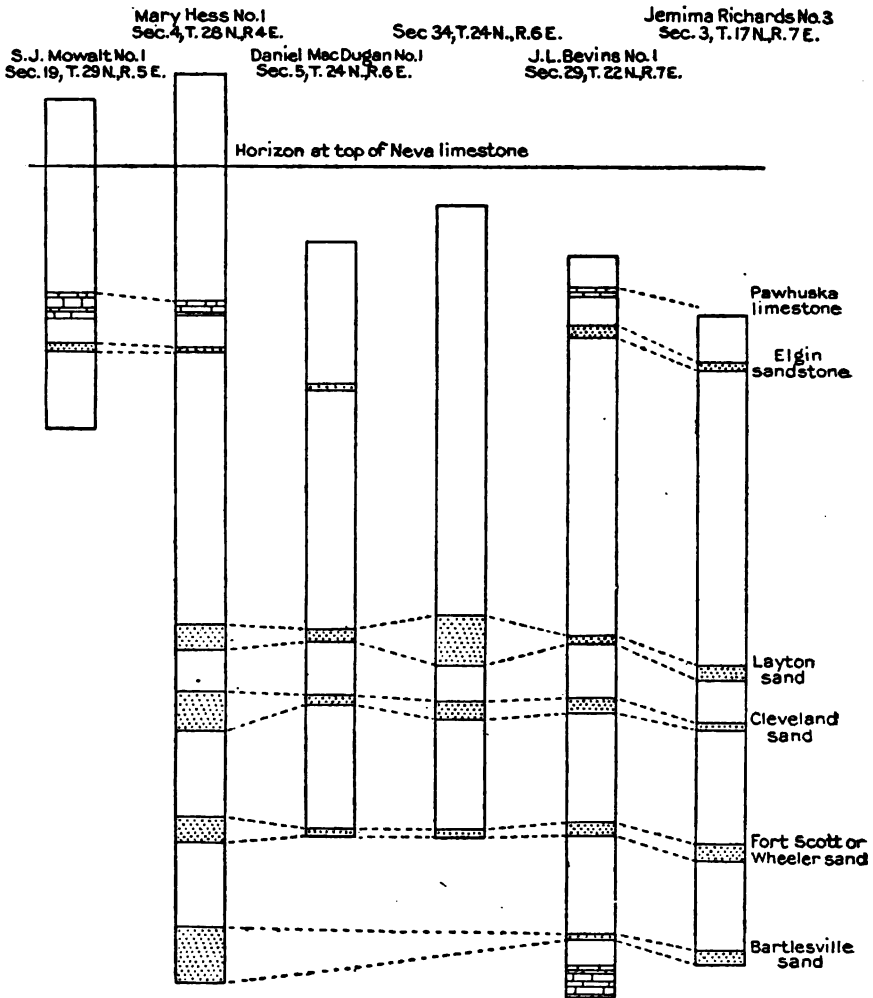


FIGURE 4.—Skeleton logs of wells in north-central Oklahoma, showing correlation of sands.

The conclusions reached agree very closely with the tentative correlations suggested by Wood¹ and by Ohern and Garrett.²

¹ Wood, R. H., Oil and gas development in north-central Oklahoma: U. S. Geol. Survey Bull. 531, p. 32, 1911.

² Ohern, B. W., and Garrett, R. E., The Ponca City oil and gas field: Oklahoma Geol. Survey Bull. 16, p. 29, 1912.

STRUCTURE.

DEFINITION.

The term "structure" as used in this report is limited to mean the form taken by the strata, whether level, warped, folded, or faulted. Geikie¹ speaks of the structure as "the architecture of the earth's crust." It must, however, be differentiated from the sculpture of the earth's surface. The practical oil man is likely to limit the application of the term to those structural features which he considers favorable for oil accumulation. When the possibilities of oil accumulation in any region are being discussed, the question is commonly asked, Is there any structure? This usage is entirely too narrow and should be discouraged.

METHOD OF DETERMINING STRUCTURE.

In order to determine the structure of a region in which the folding is very slight, as in the Foraker quadrangle, it is necessary to obtain a great number of accurately located elevations on some one key rock. The points at which these elevations are taken must, if possible, be scattered over the whole area whose structure it is desired to ascertain. As no one bed crops out over so great an area, it is necessary to take observations on the outcrops of many different beds, from which the elevation of the key rock is computed by adding or subtracting, as the case may demand, the vertical distance between the bed on which an elevation is taken and the key rock. For example, if the Neva limestone is chosen as the key rock, and the Cottonwood limestone crops out at the surface, a careful determination of the elevation of the top of the Cottonwood will be made. It has been determined by measurements made in localities where both Cottonwood and Neva limestones are exposed that the vertical distance from the top of the Neva down to the top of the Cottonwood is about 57 feet. If the elevation determined on the Cottonwood is, say, 1,100 feet, 57 subtracted from 1,100 will give 1,043 feet, the elevation of the Neva at that point.

In order to obtain the data for mapping the structure the first step is to study the rocks exposed and learn the distance between the prominent beds on which elevations may be taken and the characteristics of those beds, so that when an outcrop is encountered it will be possible to say which bed it is and just how far above or below the key rock it should be. The second step, which may often be combined with the first, is to determine the elevations at many points on the outcrops scattered over the area which it is desired to map, locating each determined point on a map and recording the bed upon which it was taken. The third step is to compute from these elevations those of the key rock as outlined above, and by connecting

¹ Geikie, James, Structural and field geology, 3d ed., p. 104, 1912.

points of equal elevation on the key rock to draw the structure contours, which show, to those who understand reading contour maps, the form of the surface of the key rock as plainly as if all the earth and rock were stripped from above it, leaving it exposed to view. (See explanation of contours below.) The structure in the deeply buried sands does not as a rule exactly parallel that shown in the beds at the surface, and hence there is always a possibility of error. When wells are drilled in this region, the well logs will furnish information by means of which the structure may be ascertained much more exactly than is possible through work with surface outcrops alone, and the structure contours may be revised. It is hoped, therefore, that when the full report for this quadrangle is prepared well logs will be available.

METHOD OF REPRESENTING STRUCTURE.

Structure may be shown graphically by structure contours, by cross sections, and by block diagrams or stereograms.

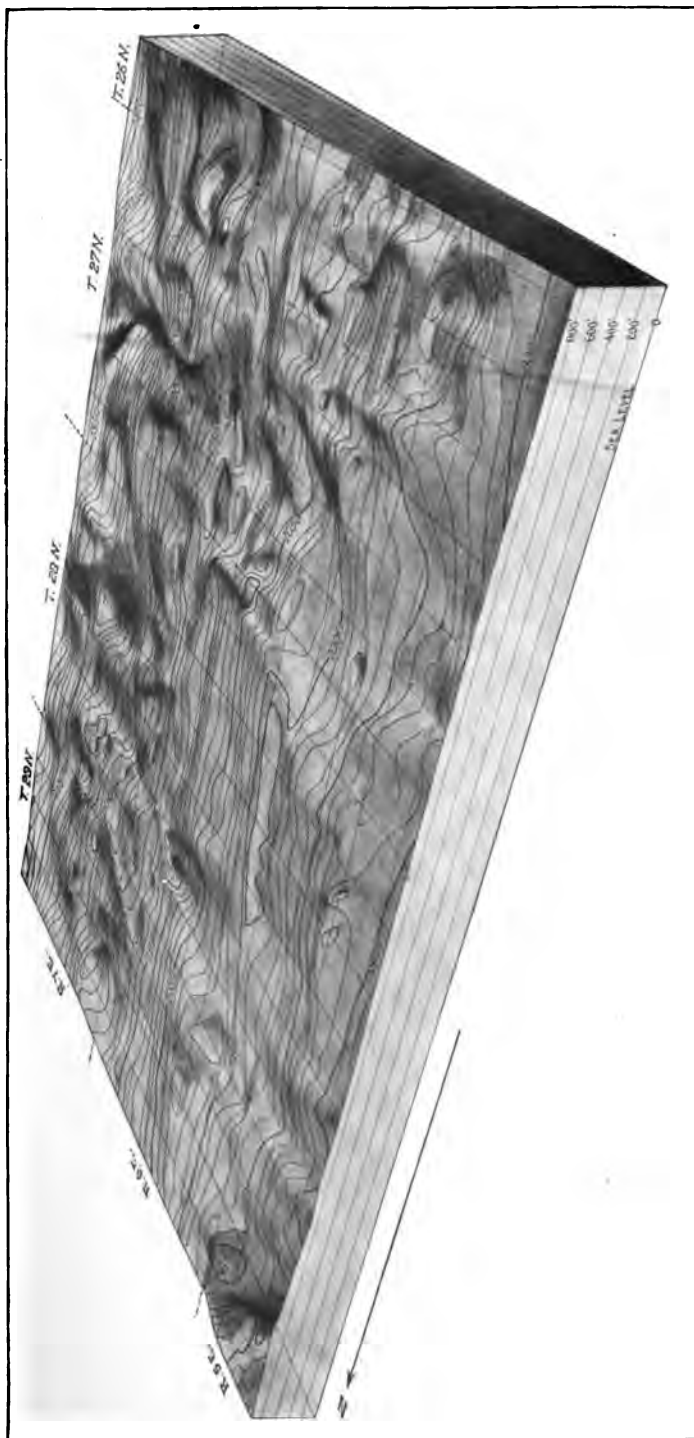
Contours.—A structure contour, like a surface contour, represents a line all points along which are uniform in elevation. Thus any point on the key rock which lies on the line represented by the contour marked 1200 is at an elevation of 1,200 feet above sea level, and any point on the line represented by the contour marked 1250 lies 1,250 feet above sea level. Every tenth contour is printed on the map in a heavy line as a matter of convenience in reading and tracing the lines. The contours are spaced at intervals of 5 feet—that is, for example, the contours between those marked 1200 and 1250 represent lines at elevations of 1,205, 1,210, 1,215 feet, etc. By means of these lines it is possible to tell to what degree and in what direction the beds dip.

Cross sections.—Cross sections show the configuration of the strata along some one line, as if the earth had been slashed with a great knife and it were possible to see the side of the gash so made.

Stereograms.—Stereograms are sketches of the surface of the key rock as reconstructed from the contours. The sketch is so shaded that the features of the surface appear to stand out in relief, just as if the surface were exposed and had been actually sketched from some point at a distance and slightly above it. The vertical scale is much exaggerated in the stereogram, so that the relief is greatly emphasized.

MAJOR STRUCTURE

The Foraker quadrangle is situated on the west flank of a great regional uplift, the center of which is occupied by the Ozark Plateau. The west flank includes a great area in southwestern Missouri, southeastern Kansas, northeastern Oklahoma, and northwest-



STEREOGRAM OF THE FORAKER QUADRANGLE, OKLAHOMA.

ern Arkansas in which the prevalent dip of the strata is to the west. In the Foraker quadrangle the general dip is almost due west at an average rate of 30 feet to the mile. However, the dip is far from uniform, being in comparatively few places exactly or even approximately 30 feet to the mile. There are many steepenings where the slope may be as much as 80 feet to the mile, and a few where it is twice that. These are compensated by flattenings where the strata may be horizontal or even dip toward the east for a short distance.

If all the earth and rock were removed from above some persistent stratum which at present lies wholly below the surface, the stratum would appear as a broad plain sloping gently westward. The uniformity of this plain would be modified by low, rounded hills with broad, slightly arched tops; low ridges, most of them running in a general westerly direction and pitching to the west; and wide, shallow valleys with smoothly curving sides. At no place would there be such abrupt rises or steep-sided depressions as are visible on the present surface. The whole plain would be characterized by smoothness and very gradual changes in the direction and degree of slope. (See Pls. II and III.)

MINOR STRUCTURE.

The term minor structure is used to indicate subordinate folds whose forms differ noticeably from that of the major structure upon which they are situated.

ANTICLINES.

BEAVER CREEK ANTICLINE.

The Beaver Creek anticline, named from its position west of Beaver Creek, is by far the most pronounced fold in the Foraker quadrangle. It is in the northwest corner of the quadrangle, and only a small part of the complete fold is shown on the map, as its northeasterly extension lies in Kansas and its southwesterly extension in Kay County, Okla.

The part lying in the Foraker quadrangle trends southwest from a point about three-tenths of a mile west of the northeast corner of sec. 14, T. 29 N., R. 5 E., and passes into Kay County near the middle of sec. 22, T. 29 N., R. 5 E. The easterly dip, which persists for about half a mile, is at an average rate of 120 feet to the mile. The maximum vertical depression caused by this easterly dip is 60 feet, which is twice that of the Foraker anticline, the next largest fold shown on the map. The shape of the Beaver Creek anticline is undetermined, as the portions lying in Kay County and in Kansas were not mapped. However, it was observed that the easterly dip is much steeper than the westerly dip, and that the length of the anticline is much greater than the breadth. On the

east flank of this fold there is a minor fold whose long axis extends about $1\frac{1}{2}$ miles and trends about N. 70° E.

The structure contours showing this anticline are based on elevations at different points on the outcrops of the Wreford and Crouse limestones. Exposures are so plentiful that no difficulty was experienced in getting sufficient data for accurate contouring.

LONE TREE DOME.

The Lone Tree dome, named from its situation just east of Lone Tree Creek, is a small upwarp about 1 mile long and half a mile wide at its widest point. The center of this dome lies about a quarter of a mile south and an eighth of a mile east of the north-west corner of sec. 28, T. 29 N., R. 6 E. Its outline is that of a triangle with rounded corners and the base toward the south. The long axis runs almost due north, and the short one almost due east. The fold is nearly symmetrical with respect to the long axis. The easterly dip is small in vertical extent, the maximum vertical descent of the beds being about 10 feet. The change from easterly dip to westerly dip in the region directly east of the fold is not perceptible, as the slopes of the beds in either direction are so slight that their approach to horizontality is difficult to detect. On the west the slope of the dome merges with that of the westward-dipping monocline, the rate of dip being about 40 feet to the mile.

Elevations on the Cottonwood limestone were used in drawing the structure contours that depict this dome.

GRAINOLA ANTICLINE.

The Grainola anticline lies west of the town of Grainola. Its highest point as expressed on the surface is about a quarter of a mile east of the southwest corner of sec. 32, T. 29 N., R. 6 E. The arch of the fold is very low, the vertical extent of the easterly dip being about 12 feet. The easterly dip persists for about half a mile before it dies out and is replaced by the prevalent westerly dip.

This fold is pear-shaped. Its longitudinal axis is about $1\frac{1}{2}$ miles long, and its transverse axis about three-quarters of a mile long at the widest point. The long axis runs in a northeasterly direction; the short axis is perpendicular to it. The structure is continued on the west in an anticlinal fold that pitches westward at a rate of 40 feet to the mile for the first half mile and at 80 feet to the mile for the next quarter of a mile.

The elevations on which the contours are based are exclusively on the Cottonwood limestone, which crops out on the flanks of the fold. The crest of the fold is occupied by a valley containing no outcrops upon which elevations could be taken.

BROOKS ANTICLINE.

The Brooks anticline is a long, relatively narrow fold whose major axis runs southward from the middle of the southwest corner of sec. 17, T. 28 N., R. 6 E., to the middle of the SE. $\frac{1}{4}$ sec. 32, T. 28 N., R. 6 E. It lies west of the Brooks School. Its length is a little over 3 miles, and its maximum width less than three-quarters of a mile. The highest point is about in the center of sec. 20, T. 28 N., R. 6 E. The elevations on the west flank of this fold were taken on the Cottonwood limestone; those on the east flank on the top of the Neva limestone. The strata along the crest are hidden by a cloak of soil, and the correctness of the contouring is dependent on the accuracy of the assumption as to the distance between the Cottonwood and Neva limestones. The assumed distance of 55 feet was obtained by projecting dips observed on the two beds and is subject to an error of not more than 10 feet. If the distance used is 10 feet too great, there would be a marked flattening of dips but no actual reversal, and the wrinkles on the west side would still be present. In other words, there would be on the west side a series of small folds with their long axes trending almost due east and having a pronounced flattening at their east ends.

The east flank is mapped as being smooth and free from cross folds, but it is probable that the apparent smoothness is due more to the lack of rock outcrops on which observations could be taken than to actual absence of minor folds.

BROWN ANTICLINE.

The Brown anticline is a large, low upwarp, the highest point of which lies about a quarter of a mile south of the northeast corner of sec. 8, T. 27 N., R. 6 E., near the Brown School. It is really more of a terrace than an anticline, as the total easterly dip amounts to only about 12 feet. The flattening is very marked, however, and is prevalent over a large area.

The axis of this anticline runs in a direction a little east of north and is a little over 2 miles long. East of the axis the strata dip eastward at a rate of about 40 feet to the mile for a distance of three-tenths of a mile, beyond which the direction of dip is reversed and the beds rise to the east at a rate of more than 50 feet to the mile. For the first mile west of the axis the dip averages about 12 feet to the mile. Farther west the slope steepens, but so gradually that at no point can a pronounced change be seen. To the north the region of low dips includes a part of sec. 32, T. 27 N., R. 6 E., where it merges into the terrace structure of the Brooks anticline. The contours on the crest and east flank of this fold were determined from

elevations taken on the upper part of the Neva limestone, and those on the west flank from elevations on the Cottonwood limestone. If there is any inaccuracy in the use of these beds it is in placing them too far apart, and the possible error does not exceed 10 feet. If the elevations on the west side of the fold are 10 feet too great the real structure is much like that shown on the map, except that the dip to the west is steeper and the anticline therefore more pronounced.

NEVA ANTICLINE.

The Neva anticline is a short, blunt fold which shows dips in three directions only—to the north, west, and south. The axis of this fold trends westward from a point about an eighth of a mile east of the southwest corner of sec. 16, T. 27 N., R. 6 E., to the quarter corner between secs. 17 and 20, N. 27 N., R. 6 E. The top of the fold is broad and flat, the east end showing a dip to the west not exceeding 10 feet to the mile. The steepest dip is on the south side of the tip, where the beds plunge to the southwest at a rate of 100 feet to the mile. On the north side of the anticline the dip is about 70 feet to the mile. The greatest change in the amount of dip occurs in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 17, T. 27 N., R. 6 E.

The contours representing this fold are based entirely on elevations taken on the top bed of the Neva limestone. Exposures are scarce, and comparatively few elevations could be obtained; therefore, while the general shape of the fold is as mapped, it is quite probable that there are minor irregularities which do not appear on the map.

HAY CREEK ANTICLINES.

The Hay Creek anticlines, named from their location near the mouth of Hay Creek, are three in number. The east-west distance from the highest point of one anticline to the highest point of the next is about a mile. The middle one is the farthest north; the western one the farthest south. In point of size they are successively larger from east to west. The elevations on which the structure contours of these folds are based are mostly on the Neva limestone, but some of them are on a limestone which lies about 23 feet below the base of the Neva. Exposures are good and no trouble was experienced in getting abundant data.

The highest point on the western anticline is about an eighth of a mile due south of the northeast corner of sec. 1, T. 26 N., R. 5 E., from which point the rocks dip gently in all directions. To the east, south, and west the dip is at the rate of 70 feet to the mile. To the north there is almost no dip for the first half mile, and then the strata dip north at about 50 feet to the mile. The dip on the east persists in that direction for about half a mile and then reverses, the beds rising gently toward the east. The flattened top of this dome is

less than half as wide as it is long. The long axis trends a little east of north throughout most of the length, but swings sharply northwest at the north end. The long sides bow in toward each other in the middle and the ends are rather blunt.

The highest point of the middle Hay Creek anticline is about a quarter of a mile due south of the northwest corner of sec. 32, T. 27 N., R. 6 E., from which point the axis trends a little east of north and west of south. The length of the axis is about $1\frac{1}{2}$ miles. The outline of this fold is something like the blade of a knife which lies with its point to the north, the length being about three times the width. The dip either east or west of the axis is at the rate of about 60 feet to the mile. That on the east side has a total vertical amount of only 12 feet, however, the horizontal distance over which it extends being short. To the north and south the dips are very gentle and merge into the general westerly dip of the region without any perceptible change.

The eastern Hay Creek anticline is the smallest of the three folds. Its highest point lies a little southwest of the quarter corner between secs. 32 and 33, T. 27 N., R. 6 E. In outline it is like the blade of a narrow, round-ended, round-shouldered trowel. The long axis of the anticline points a little east of north. It is a little less than a mile long, and its greatest width is about a quarter of a mile. The easterly dip is insignificant, amounting to a little over 5 feet at its point of greatest development. To the west, however, the beds dip steeply for this region, showing for about a quarter of a mile a grade of 100 feet to the mile. The change in dip at the upper end of this relatively steep slope is very pronounced, giving the structure more the form of a terrace than that of an anticline.

WAMSLEY CREEK ANTICLINE.

The Wamsley Creek anticline is a low, irregular fold south of Wamsley Creek. It is made up in reality of two distinct low folds or structural swells whose highest points appear at the surface in the middle of the SE. $\frac{1}{4}$ sec. 25, T. 27 N., R. 6 E., and about one-tenth of a mile south of the corner of secs. 25, 26, 35, and 36. In shape this fold is like a V having thick, uneven sides and pointing northwest. The highest points occur at about the middle of each side and are separated by a narrow, shallow depression. The long axis of the east side of the fold points about N. 40° W., and that of the west side about N. 30° W. The fold, considered as a whole, is about 2 miles long and 1 mile wide. The actual reversal of dip is very slight, the maximum eastward descent being about 10 feet. The dip to the east is at the rate of about 40 feet to the mile, and that to the west has a maximum of about 80 feet to the mile.

The structure contours showing this fold are based on elevations taken on several beds of the Foraker limestone. Exposures were abundant and the beds could be accurately correlated, so there is small doubt about the exact form of this anticline.

POTATO CREEK ANTICLINE.

The name Potato Creek anticline has been given to a pronounced fold whose highest point is in the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 32, T. 27 N., R. 7 E., south of Potato Creek. This anticline is irregular in outline, forming an uneven oblong with ends and sides only approximately parallel. The major axis is about $1\frac{1}{2}$ miles long and trends about N. 20° E. The greatest width of the anticline is near the north end and amounts to a little more than a mile. The top of the fold is almost flat and covers an area of about half a square mile. It pitches to the north at an average rate of 70 feet to the mile, and the beds dip to the west at the same rate. Toward the south the dip is not so pronounced, the maximum drop being about 40 feet to the mile. On the east there is a drop of 15 feet at a rate of 120 feet to the mile, followed by a sharp reversal, the easterly dip being met by a westerly dip of equal steepness. It is possible that a small fault separates the beds here, although there is no evidence of such a break except the abrupt reversal of dip.

On the west flank of the anticline, about a mile southwest of the summit, there is a structural terrace. The dip to the west flattens to about 10 feet to the mile and then steepens abruptly to almost 150 feet to the mile. The front of this terrace extends along the east line of sec. 1, T. 26 N., R. 6 E.

NORTH BIRD CREEK ANTICLINE.

The North Bird Creek anticline is a long narrow fold whose axis extends southwestward from a point three-tenths of a mile south of the northwest corner of sec. 12, T. 27 N., R. 7 E., near North Bird Creek, to a point about one-tenth of a mile south of the quarter corner between secs. 17 and 20, T. 27 N., R. 7 E. The dips on this fold are to the north, west, and south. On the east the fold merges into the general westward-dipping monocline without any perceptible change in the general dip. The greatest flattening shown on this fold is in the southwest corner of sec. 11, T. 27 N., R. 7 E., where the average dip is about 15 feet to the mile toward the southwest. The steepest dip is at the very tip of the fold, where the beds slope westward at an average of 110 feet to the mile. At one place on the south side of the fold the dip is as steep as that shown on the tip, but only for less than one-fifth of a mile.

Most of the elevations on which the contours of this fold are based were taken on beds in the Foraker limestone, but some of them were taken on the sandstone which lies about 43 feet below the base of the Foraker. Outcrops were abundant and correlations could be easily and accurately made.

FORAKER ANTICLINE.

The Foraker anticline is a low upwarp, the crest of which is just northwest of the southeast corner of sec. 21, T. 28 N., R. 7 E., northeast of Foraker. The outline of this low swell is much like the bottom of a flatiron with a blunt rounded point and the back side of the flatiron slightly curved in toward the center. The major axis, which trends a little south of west, is about $2\frac{1}{2}$ miles long. The greatest breadth of the anticline is about $1\frac{1}{2}$ miles, at the east end.

The dips to the north, west, and south are fairly uniform and about 75 feet to the mile. On the east flank of the fold the dip to the east averages 25 feet to the mile. The top of the anticline, about a quarter of a square mile in extent, is very flat, and dips in any direction are hard to detect.

A good deal of difficulty was experienced in mapping this anticline, as continuous outcrops are rare, and the dip to the east was determined not by continuous tracing of a single bed but by correlating scattered outcrops. It could not be proved that much of the apparent easterly dip is not due to a fault, but the fact that no faults or indications of faults were seen elsewhere in the quadrangle would make the existence of a fault here seem very improbable. It is, however, possible to say definitely that to the north the strata are not broken. Of the exact structure south of the crest of the fold very little could be ascertained, as there are practically no rock outcrops in that area. It was possible to determine the general dip, however, and although the structure on the south side is probably not so regular as the map indicates, it is unlikely that the mapping diverges greatly from the true structure.

ELM CREEK ANTICLINE.

The Elm Creek anticline is a small upwarp lying on the headwaters of Elm Creek, in the W. $\frac{1}{2}$ sec. 9, T. 27 N., R. 7 E. The axis of the fold is about $1\frac{1}{2}$ miles long and trends about N. 25° E. The anticline is really made up of two small domes which are separated by a slight saddle. These domes are small oval swellings of nearly equal size. Their major axes have a length of half a mile and their minor axes a length of a little more than a quarter of a mile.

The dips on all sides of the fold are gentle. East of the principal axis the beds dip eastward for less than a quarter of a mile, to a point where the slope is reversed, and the highest point of any bed

in the anticline is less than 15 feet above the lowest point that the same bed may reach east of the anticline. West of the principal axis the beds slope away from it at a rate of about 35 feet to the mile for a quarter of a mile and at 100 feet to the mile for about a quarter of a mile more before the dip merges into the general westward dip of the region.

The Red Eagle limestone crops out over the surface of this anticline, and the structure contours are based on elevations on the top of this bed.

ANTELOPE CREEK ANTICLINE.

The Antelope Creek anticline lies in secs. 10 and 11, T. 27 N., R. 6 E., just south of Antelope Creek. It is a transverse fold with a curving axis trending about N. 75° W. The general outline of the compound structure is something like that of a two-pronged tooth with the prongs pointing west.

The dips to the north, west, and south are at the rate of 60 feet to the mile. No dip to the east appears except in one small area on the very crest of the wrinkle. Here the beds are inclined to the east for a horizontal distance of about one-eighth of a mile, in which there is a depression of 10 feet.

The structure contours for this fold were determined from elevations on the Neva limestone, which crops out along the flanks of the fold.

SYNCLINES.

No detailed description is given of the synclines, as the purpose of this paper is primarily to point out those features which are of economic importance with relation to oil and gas, and a syncline is such a feature only where oil-bearing strata do not carry water. As such a condition has not been found to exist in any of the oil pools in the region surrounding the Foraker quadrangle, it is fair to assume that the sands underlying the surface in this quadrangle carry water. A mention of the positions of the axes of the larger synclines may be of some value, however, as the bottoms of these structural troughs are theoretically the most unfavorable places for accumulations of oil and gas, and they should accordingly be avoided in wildcatting operations.

Synclines occur north and south of the Foraker anticline. The axis of the one to the north strikes about N. 75° E. and extends from the quarter corner between secs. 24 and 25, T. 28 N., R. 6 E., to a point about 500 feet south of the middle of sec. 16, T. 28 N., R. 7 E. The one on the south is a sharper fold but is not so long. The axis of this trough trends northeastward from a point a little northwest of the middle of sec. 33, T. 28 N., R. 7 E. About 1,000 feet south of

the middle of sec. 27, T. 28 N., R. 7 E., the axis divides, one branch continuing northeast for about a mile and the other trending a little south of east for about $1\frac{1}{2}$ miles, to the place where the syncline dies out.

Just south of the North Bird Creek anticline there is a small, well-defined syncline whose axis begins 1,000 feet west of the southeast corner of sec. 15, T. 27 N., R. 7 E., and trends northeastward to a point 1,000 feet north of the southwest corner of sec. 12, T. 27 N., R. 7 E.

A large, pronounced syncline lies south of the one just described, and its axis, which is slightly curved, extends from a point 3,000 feet southwest of the northeast corner of sec. 29, T. 27 N., R. 7 E., to the middle of sec. 24, T. 27 N., R. 7 E., where it passes out of the quadrangle.

In the southwest corner of the quadrangle there is a well-defined syncline whose axis extends from a point 1,000 feet north of the southeast corner of sec. 26, T. 27 N., R. 5 E., to a point 2,300 feet south of the northwest corner of sec. 29, T. 27 N., R. 6 E., just northwest of the middle Hay Creek anticline.

Just north of the Antelope Creek anticline there is a short syncline with a curved axis about a mile long extending from the southwest corner of sec. 3, T. 28 N., R. 6 E., to a point about 1,000 feet east of the southwest corner of sec. 12, T. 28 N., R. 6 E.

East of the Beaver Creek anticline there is a syncline whose axis trends northeastward from the quarter corner between secs. 27 and 34, T. 29 N., R. 5 E., to the middle of sec. 23, T. 29 N., R. 5 E.

In the north-central part of the quadrangle there is a pronounced structural depression with an axis trending in a general southeasterly direction from the quarter corner between secs. 25 and 26, T. 29 N., R. 6 E., to the middle of the NW. $\frac{1}{4}$ sec. 5, T. 28 N., R. 7 E.

Besides the synclines described above there are many small ones whose influence on oil and gas accumulation is minor and in some cases probably negligible.

ACCUMULATION OF OIL AND GAS.

The various theories which attempt to give the reasons for the accumulation of hydrocarbons at certain selected points in the rocks will not be discussed in this paper. The essential thing is a knowledge of certain definite rules which repeated observation has shown are followed by the oil and gas in their journey to the points where pools are found, and of the conditions under which such accumulations of oil and gas are known to occur.

Gas, in its journey through the rocks, tends always to reach the highest possible point, regardless of the degree to which the rocks are saturated with water. Petroleum also persistently climbs the

slope of inclined water-containing strata, if they are pervious enough to permit its passage. If water is absent, however, the direction of movement is reversed and the oil will tend to travel down the dip of the containing beds.

An oil pool must occupy a reservoir capable of containing the oil and so situated that the oil can not escape until the pool is tapped by the drill. Such reservoirs are usually formed by porous beds of rock confined beneath impervious beds. The porous bed is usually a sandstone, although it may be a limestone or even an igneous rock; the impervious bed is commonly a shale. Although a shale is not absolutely impervious, and under some conditions petroleum will undoubtedly travel through it, a shale cap over a porous sandstone is sufficiently impassable to oil to make possible the largest accumulations of petroleum and natural gas that have been discovered up to the present time.

Where the succession of strata is such that a suitable reservoir is provided, oil accumulations have been found to be in direct relation to three factors. These are the attitude of the strata, whether horizontal or tilted; the degree to which the strata are saturated with water; and the permeability of the strata, which depends on their porosity and on the size of the openings between their grains or particles. Any one of these three factors may be the dominating one, but the first named has appeared to be much the most influential. This may be due, in part at least, to the fact that comparatively little study has been given to the third, largely because of the difficulty in obtaining data that bear on it. Also, while the third factor is doubtless important, there is no means of telling anything about it in untested territory, so that even an absolutely clear understanding of its action would be of little assistance to the geologist in locating promising territory for prospecting. The same thing is true, to a less extent, as to the saturation of the strata with water. A single wildcat well goes far toward determining this factor. In the present state of knowledge, therefore, the attitude of the strata is the most practical and important indication available to the prospector.

If the influence of the permeability of the strata which contain the oil is disregarded, there are four principal conditions which should be discussed, each taking into consideration the attitude of the beds and the degree to which they are saturated with water.

1. Where the strata are approximately level and contain water oil and gas accumulations of commercial importance appear to be rare. The controlling factor of those which have been found appears to be the porosity of the bed that contains the oil or gas, the pools selecting the most porous lenses or "streaks" and occupying them to the exclusion of other parts of the bed. Pools of this type are particularly likely to occur where there are great quantities of

oil in the rocks, and it is presumable that the oil in the pools is but a small fraction of that which is disseminated through the rock in quantities too small to repay drilling. It is likely that some of the oil fields of Washington and Nowata counties, Okla., belong to this type. The discovery of such accumulations is always the result of chance drilling, as surface features can give no indication of their presence.

2. Where the strata are approximately level and "dry" oil might accumulate in "pay streaks" such as are described in the preceding

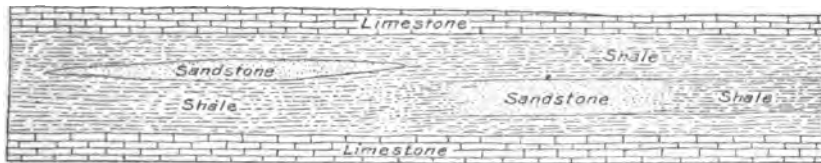


FIGURE 5.—"Pay streaks" of oil in level strata.

paragraph and shown in figure 5. Some contend that even where drill holes are apparently dry the microscopic interstices between the grains of the rocks contain water which is prevented from escaping by the capillary attraction exerted by the minute openings that hold it. No known oil pools have been shown to have the conditions described, and the possibility of such accumulations may be disregarded.

3. Inclined strata containing water present the conditions most commonly found in oil fields and accordingly by far the most important. These conditions are known to exist in the most productive districts of Oklahoma, such as the Cushing field,¹ the Healdton field,² and the Ponca City field.³

The oil travels up the slope formed by the rising strata until some obstacle which it can not pass intervenes and stops it. This obstacle may be furnished by the pinching out of the bed. In that case a condition such as is shown in figure 6 will result, the pool forming at the highest point of the porous bed which it can reach. The limits of such a pool can not be even guessed from anything which appears at the surface of the ground, its discovery being dependent on chance drilling.

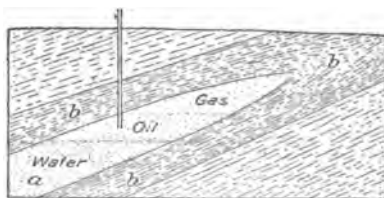


FIGURE 6.—Cross section illustrating theoretical pinching out of oil-bearing strata. *a*, Sandstone; *b*, shale.

¹ Buttram, Frank, The Cushing oil and gas field, Okla.: Oklahoma Geol. Survey Bull. 18, 1912.

² Wegemann, C. H., and Heald, K. C., The Healdton oil field, Carter County, Okla.: U. S. Geol. Survey Bull. 621, pp. 13-30, 1916 (Bull. 621-B).

³ Ohern, D. W., and Garrett, R. E., The Ponca City oil and gas field: Oklahoma Geol. Survey Bull. 16, 1912.

In most of the large fields, however, the obstacle to the upward movement of the oil and gas is produced by the flattening

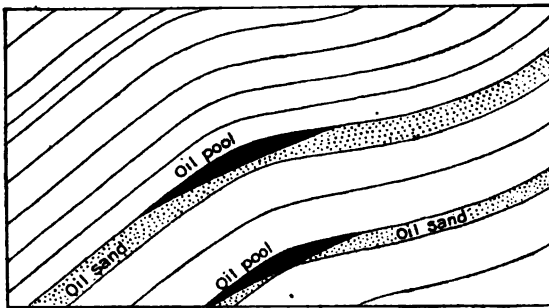


FIGURE 7.—Cross section illustrating theoretical accumulation of oil on terrace.

or actual reversal of direction of the dip of the oil-bearing beds. The flattening produces a terrace, as shown diagrammatically in figure 7. The reversal indicates an anticline, as shown in figure 8. Either one may cause an accumulation of oil. In the Cushing, Healdton,

and Ponca City pools there is an actual reversal of dip of considerable amount. This is the condition which is generally held to be most favorable and upon which recommendations for drilling are most commonly based. There are no recorded oil pools in Oklahoma occurring in structural terraces. That accumulations may occur in such a position, however, is altogether probable, as they are recognized in other parts of the United States.

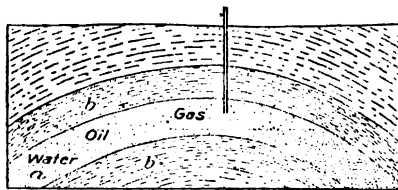


FIGURE 8.—Cross section illustrating theoretical accumulation of oil in anticline. *a*, Sandstone; *b*, shale.

A third way in which the upward journey of oil and gas may be stopped is through the agency of faults. If there is a displacement of the strata which results in the porous bed being broken

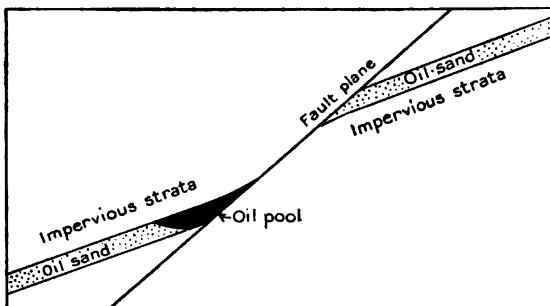


FIGURE 9.—Cross section illustrating theoretical accumulation of oil due to faulting.

off and left abutting against an impervious bed, the migration of the oil and gas will be effectually stopped unless the fault leaves an open fissure along which escape is possible. There are several considerable accumulations of oil and gas which are believed to have been caused by

faults. Some of those in southern Osage County are believed to be of this type.¹ This condition is graphically shown in figure 9.

¹ Wood, R. H., personal communication.

4. Inclined and dry strata have never been certainly recognized in regions where oil has been found. This condition is believed to exist, however, and to be the cause of the accumulation of oil in the lowest parts of the containing porous rocks. The theoretical relations of such an oil accumulation and the strata are shown in figure 10. The petroleum gathers in the porous bed, travels down the slope, and is collected in the bottoms of troughs or synclines formed by the folding of the strata. In the few known oil pools found in this position the containing strata have yielded no water, a fact which appears to bear out the theory. No pools of this type occur in Oklahoma, so far as is known to the writer.

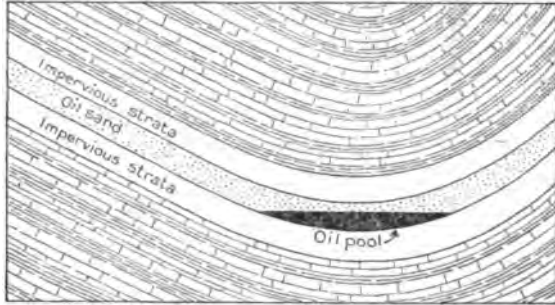


FIGURE 10.—Cross section illustrating theoretical accumulation of oil in syncline.

RECOMMENDATIONS FOR PROSPECTING.

There is a distinct order of preference which should be considered in the exploration of the anticlines of the Foraker quadrangle. Should a fold which is favorably located and structurally suited to contain oil and gas be found to contain no such accumulation, the presence of pools in adjacent territory structurally less favorable would be much less probable. Prospecting should not be indiscriminate but should first test thoroughly the localities where the structure appears most favorable, and if one of these localities fails to yield oil and gas, prospecting should be at least temporarily moved to a point some distance away.

However, no fold should be condemned on the evidence offered by a single hole. The attitude of the strata is by no means the only factor governing the accumulation of oil and gas, and some one of the others may interfere so strongly that a fold which is otherwise pronouncedly favorable for such an accumulation will prove barren. One of the most potent of these other factors is believed by the writer to consist in the porosity and the nature and size of the openings in a bed which the oil and gas can occupy. For accumulations of gas the porosity is the more important. For accumulations of oil large interstices between grains are probably more essential than high porosity. These factors can vary greatly within a short dis-

tance, and that is one of the principal reasons for the above recommendation that at least two test holes should be drilled before an apparently favorable fold is abandoned.

In the Foraker quadrangle the anticline which offers the best structural conditions for the accumulation in commercial amount of oil and gas is the Beaver Creek anticline, in the extreme northwest corner. The best point for prospecting is on the very crest of the fold, which is a little south of the center of sec. 15, T. 29 N., R. 5 E. A well drilled here should reach the horizon of the Bartlesville sand at a depth of about 3,240 feet. In case oil or gas in considerable quantities are not found in the initial test, a second should be drilled about half a mile south and a quarter of a mile west from the first. Failure to find oil or gas in the Beaver Creek anticline would have little bearing on the possibility of their accumulation in other folds in the Foraker quadrangle, as the Grainola anticline, which is the nearest one of any great promise, is about 4 miles from the Beaver Creek anticline and has ample gathering ground to supply hydrocarbons sufficient for any accumulation which it would be likely to hold.

The fold which appears to be second in promise is the Foraker anticline. This anticline, though small compared to those in many of the Oklahoma oil fields, still offers all the structural conditions that are necessary for the formation of an oil pool of considerable proportions. Owing to the comparatively low dip on all sides of this fold a hole sunk on the top of the fold, which is shown on the surface, would strike the highest point of the continuation of this fold at reasonable depth. Although it is impossible to say that this fold has the same shape underground as it shows at the surface, the outlines should be roughly the same, and the best that can be done is to choose the point at which the surface indications are the most promising. It is recommended that the first test hole on this anticline be sunk 600 feet west and 100 feet north from the southeast corner of sec. 21, T. 28 N., R. 7 E. It should reach a depth of at least 2,800 feet. If the first test fails to get oil or gas, a second should be drilled about 500 feet north of the quarter corner between secs. 21 and 28. The failure of these tests would tend to indicate the absence of accumulations of oil and gas not only in the Foraker anticline, but also in the Elm Creek anticline. If the more pronounced fold does not contain an accumulation of oil, it is unlikely that such an accumulation has formed under the less favorable structural conditions present in the smaller fold.

Third in importance is the Potato Creek anticline. This fold, while less well developed than the Foraker anticline, still offers all the structural requisites for a large oil pool. The dips on the several

sides of this fold do not differ in degree enough to affect the accumulation of oil, and the best point for prospecting is the highest point of the fold as expressed on the surface. This point is roughly 500 feet east and 200 feet north from the southwest corner of sec. 32, T. 27 N., R. 7 E. Should a hole at this point fail to show oil and gas in considerable quantity, a second one should be drilled about 2,000 feet due south of the quarter corner between secs. 29 and 32. These tests should reach a depth of at least 2,800 feet, which should bring them to the horizon of the Bartlesville sand. A good showing of oil at that depth would justify drilling 100 or 200 feet deeper. In case the Potato Creek anticline is barren of petroleum or gas, prospecting the near-by Wamsley Creek anticline would not be advisable unless work to the west should disclose producing territory.

The three localities mentioned above are structurally the most favorable ones in the quadrangle. The order of importance of the other folds that have been described in detail is believed by the writer to be as follows: Western Hay Creek, Grainola, Lone Tree, Brown, North Bird Creek, Antelope Creek, Elm Creek, Wamsley Creek, middle Hay Creek, eastern Hay Creek, Brooks, and Neva. The best points for drilling are on the highest points of the folds, which are mentioned in the detailed descriptions. In deciding on the relative importance of these folds weight was given not only to their expression on the structure map, but also to the completeness of the data on which the structure contours are based.

PROBABILITY OF FINDING OIL AND GAS IN THE FORAKER QUADRANGLE.

There can be little doubt that oil and gas will be found in the Foraker quadrangle. Producing fields, some of them of immense yield, have been opened to the north, east, south, and west of this area. Oil has been found in commercial quantity in Kay County, less than 2 miles from the west edge of the quadrangle, and also in Kansas about a mile from the north line. Various test wells near the quadrangle have established the fact that there are in this region numerous sands which are excellently fitted to hold accumulations of oil and gas. The anticlinal structure, while less pronounced than that in most of the largest oil fields of Oklahoma, is quite as well developed as that in many of the smaller fields, both in Oklahoma and elsewhere. In short, all the factors which conduce to large accumulations of petroleum are believed to be present here, and it is most probable that drilling will disclose pools in at least some of the favorable places described in the preceding pages.



DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 641—C

POSSIBILITIES OF OIL AND GAS IN NORTH-CENTRAL MONTANA

BY

EUGENE STEBINGER

Contributions to economic geology, 1916, Part II
(Pages 49-91)

Published July 17, 1916



WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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POSSIBILITIES OF OIL AND GAS IN NORTH-CENTRAL MONTANA.

By EUGENE STEBINGER.

INTRODUCTION.

The search for oil and gas in Montana has become very active, and there is an insistent demand for information concerning the occurrence of these substances in the State. The extension into Montana of the Wyoming fields that are producing high-grade oils, the development of valuable gas fields in southern Alberta, the discovery of some oil within a few score miles of the northern boundary of Montana, and, finally, the recent drilling in of a large gas well at Havre, in Hill County, have led petroleum engineers and oil operators to give serious attention to "wildcatting" in this State. The thick bodies of Upper Cretaceous shale with which most of the oil and gas in both Wyoming and Alberta are associated are known to be continuous between these two localities under the plains portion of Montana, making it apparent that favorable structural features, in this area especially anticlines and domes similar to those that are productive in Wyoming and Alberta, offer a chance of success with the drill.

The purpose of the report here presented is to summarize all the available data concerning the possible occurrence of oil and gas in a considerable area in the north-central part of Montana, extending from the latitude of Great Falls northward to the international boundary. By no means all of this area has been searched for favorable structures, but the general character of the Cretaceous formations present under most of the area is well known. Furthermore, it is proposed to point out a number of anticlines and other upward-arching structures occurring in parts of Hill, Chouteau, Blaine, and Fergus counties which, according to experience at Havre, seem to be favorable for prospecting.

The facts observed seem to warrant the statement that considerable gas territory, on a scale comparable with the Alberta fields, may

be found and also that the area shows some probability of yielding oil. It can not be too strongly emphasized, however, that a rational search for oil and gas in the State should begin with operations in the areas where the rocks are most strongly arched. Only after these areas have been successfully prospected should the areas be tested which involve a much greater risk, namely, those in which the deformation of the beds is less pronounced or the bedrock is concealed by glacial drift.

LOCATION AND SURFACE FEATURES.

The part of north-central Montana herein described extends southward from the international boundary a distance of about 106 miles to the latitude of Great Falls and eastward a distance of 192 miles from R. 8 W. to R. 24 E. of the General Land Office surveys for Montana. (See fig. 11.) The area contains about 22,000 square

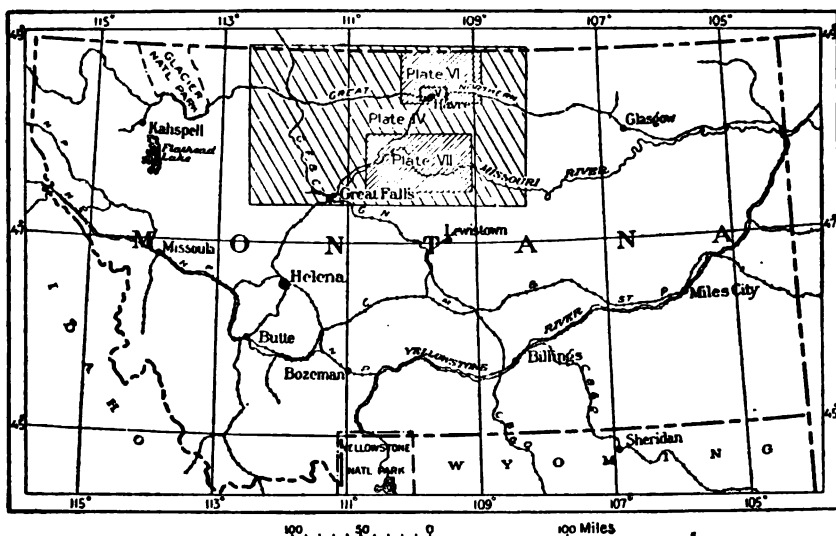


FIGURE 11.—Index map of Montana showing areas covered by Plates IV-VII.

miles. The principal towns are Great Falls, Fort Benton, and Havre. The area includes all of Blaine, Hill, Toole, and Chouteau counties and parts of Fergus, Cascade, Teton, and Phillips counties. Plate IV is a geologic sketch map of the entire region.

For the most part the region is a treeless plains country, slightly rolling and covered with glacial drift. Along the principal streams, Missouri and Milk rivers and their tributaries, there are extensive areas of badlands, affording excellent exposures of the Cretaceous formations present. The region is further diversified by four small mountain groups, the Sweetgrass Hills, Bearpaw Mountains, Little

Rocky Mountains, and Highwood Mountains, which are from 20 to 40 miles across and rise island-like 2,000 to 4,500 feet above the general level of the plains. They are partly forest covered and well watered, in contrast with the semiarid plains that surround them.

BASIS OF THE REPORT AND MAPS.

Only a small part of the region here described has been examined with a view to reporting specifically on its oil and gas possibilities. Many of the map data and other details presented are taken from work done during the last 10 years by members of the Geological Survey while studying the coal resources of the region. These surveys cover about a quarter of the area here described. In the examinations for coal the general features of the geology, especially near the coal outcrops, were carefully mapped, but naturally many details that are of prime importance in the search for oil and gas, particularly those pertaining to structure and to possible surface showings of oil and gas, were not recorded. Fisher¹ in 1906 examined the area extending from the vicinity of Great Falls northwestward to and beyond Teton River. Much of the information concerning the Kootenai formation in Montana is based on his observations. In 1908 and 1909 Pepperberg² mapped the area along the Milk River valley from Harlem to a point a few miles west of Havre. Many of the data on Plate V, showing the geology in the vicinity of Havre, and on Plate VI, showing the tilted and folded rocks lying south of T. 35 N., were compiled from Pepperberg's maps and notes. In 1912 Bowen³ examined 10 townships lying southeast of Big Sandy between Missouri River and the Bearpaw Mountains and also a considerable area near the east end of the mountains in the vicinity of Cleveland. The data on the area lying north of Missouri River shown on Plate VII are taken from Bowen's reports. E. R. Lloyd in 1914 mapped all the area south of Missouri River shown on Plate VII extending eastward to R. 17 E. Lloyd's work has not been published and the descriptions of the area here given are taken from his original notes and maps. During the summer of 1915 the writer, assisted by Wendell P. Woodring and Julian D. Sears, examined the area in the vicinity of Winifred, in northern Fergus County, and

¹ Fisher, C. A., *Geology of the Great Falls coal field, Mont.*: U. S. Geol. Survey Bull. 356, 1909; *Geology and water resources of the Great Falls region, Mont.*: U. S. Geol. Survey Water-Supply Paper 221, 1909.

² Pepperberg, L. J., *The Milk River coal field, Mont.*: U. S. Geol. Survey Bull. 381, pp. 82-107, 1910; *The southern extension of the Milk River coal field, Chouteau County, Mont.*: U. S. Geol. Survey Bull. 471, pp. 359-383, 1912.

³ Bowen, C. F., *The Cleveland coal field, Blaine County, Mont.*; *The Big Sandy coal field, Chouteau County, Mont.*: U. S. Geol. Survey Bull. 541, pp. 338-378, 1914.

then spent the remainder of the season mapping the northern portion of the Milk River coal field, lying in the tiers of Tps. 35 to 37 N. Gas was discovered at Havre during this period, and a few days were spent in that vicinity. A description by the writer¹ of the geology of the northwestern part of the region here considered has already been published.

GEOLOGY.

SEDIMENTARY ROCKS.

GENERAL FEATURES.

The sedimentary rocks in north-central Montana range in age from Cambrian to Recent. The formations, older than the Kootenai formation (Lower Cretaceous), however, are exposed only in the mountain uplifts and offer meager prospects of yielding either petroleum or natural gas. These older rocks, of Jurassic or earlier age, are best exposed in the Little Rocky Mountains and the Sweetgrass Hills. They are mainly hard, compact limestones that are not known to be petroliferous at any point in the region. This character, together with the fact that in the plains areas they generally lie too deep to be readily reached with the drill, makes them of little interest to the oil and gas prospector. In southern Montana and Wyoming these older formations contain a larger proportion of shale, which in places attains a considerable thickness, and there they may be of some importance as a source of oil and gas.

The extensive plains of northern Montana are underlain within reasonable drilling depth almost exclusively by Lower and Upper Cretaceous formations, and the sandstone beds associated with the thick bodies of shale in these rocks offer the best reservoirs for oil and gas in the region. Generalized sections showing the sequence and character of the formations, one for the eastern part and one for the western part of the region, are given below. These sections are also shown graphically on Plate IV.

¹ Stebinger, Eugene, Geology and coal resources of northern Teton County, Mont.: U. S. Geol. Survey Bull. 621, pp. 117-156, 1915 (Bull. 621-K).

Formations exposed in the plains of north-central Montana east of the 112th meridian in the area described in this report.

System.	Series.	Group and formation.	Thickness (feet).	Character.	
Quaternary.	Recent.	Alluvium.		Silt, sand, and gravel along flood plains of larger streams.	
	Pleistocene.	Glacial drift.	0-200	Bowlder clay, gravel, and lake silt and clay. Contains bowlders and cobbles of granite, gneiss, quartzite, etc., transported from the northeast.	
Tertiary.	Eocene.	Fort Union formation.	" 700+	Clay shale, sandstone, and coal beds. Present only in small areas. Poorly exposed.	
Tertiary (?).	Eocene (?).	Lance formation.	700-800	Alternating gray clay shale and sandstone with irregular coal beds. Present in relatively small areas only.	
Cretaceous.	Upper Cretaceous.	Montana group.	Bearpaw shale.	500-800	Dark-gray clay shale with a few limestone concretions. Contains many marine shells. Forms a subdued, rounded topography and gumbo soil.
			Judith River formation.	450-550	Light-gray clay and clay shale with irregular beds of gray or brown sandstone, and coal beds. Contains many oyster and other shells besides fossil bones.
			Claggett shale.	350-500	Like the Bearpaw in character of rocks and fossils, except for the occurrence of sandy beds near the top.
			Eagle sandstone with Virgelle sandstone member at base.	250-400	Upper part gray clay shale and sandstone with coaly shale and thin coal. Lower part white to buff thick-bedded massive sandstone, Virgelle sandstone member. <i>Contains gas in the Havre district.</i>
			Colorado shale.	1,500-1,700	Bluish-gray to black shale with a few limestone concretions. Contains many marine shells. Includes three or four sandy beds 5 to 70 feet thick in lower 800 feet. <i>Probably contains gas and oil in some localities of favorable structure.</i>
		Lower Cretaceous.	Kootenai formation.	400-600	Red clayey shale and irregular gray sandstone with a few thin beds of limestone. Contains coal near the base and fossil plant remains of fresh-water origin. <i>Probably contains gas and oil in some localities of favorable structure.</i>

^a Estimated.

Formations exposed in the plains of north-central Montana west of the 112th meridian in the area described in this report.

System.	Series.	Group and formation.		Thickness (feet).	Character.
Quaternary.	Recent.	Alluvium.			Silt, sand and gravel along flood plains of larger streams.
	Pleistocene.	Glacial drift.		0-200	Bowlder clay, gravel, and lake silt and clay. Contains bowlders and cobbles of granite, gneiss, quartzite, etc., transported from the northeast.
Cretaceous.	Upper Cretaceous.	Montana group.	Bearpaw shale.	450-550	Dark-gray clay shale with a few limestone concretions. Contains many marine shells. Forms a subdued, rounded topography.
			Two Medicine formation.	1,600-2,100	Gray to greenish-gray clay and soft irregular sandstone, which is most abundant in the lower 250 feet. In places thin beds of red clay and nodular limestone. Contains an abundant reptilian fauna of Judith River types, besides leaves and shells. Contains coal beds near the base and at the top.
			Virgelle sandstone.	200-290	Gray to buff coarse-grained, much cross-bedded massive sandstone, with many ferruginous concretions in upper half. In lower half slabby gray sandstone, becoming shaly toward the base.
		Colorado shale.	1,600-1,750	Bluish-gray to black shale with a few limestone concretions. Contains many marine shells. Includes three or four sandy beds 5 to 70 feet thick in lower 800 feet. <i>Probably contains gas and oil in some of the areas of favorable structure.</i>	
	Lower Cretaceous.		Kootenai formation.	600-700	Shale, red in upper part, but remainder grayish to black. Contains irregular sandy beds up to 100 feet thick. Fresh water. <i>Probably contains gas and oil in some of the areas of favorable structure.</i>

As shown by the tables given above, the differences between the geologic sections of the eastern and western parts of the region occur in the Montana group in the interval between the Virgelle sandstone and the Bearpaw shale. This is due to the fact that the marine invasion during which the Claggett shale was deposited in the east did not extend westward beyond the 112th meridian. An account of these relations has already been published.¹

¹ Stebinger, Eugene, The Montana group of northwestern Montana: U. S. Geol. Survey Prof. Paper 90, pp. 61-68, 1915 (Prof. Paper 90-G).

FORMATIONS IMPORTANT IN THE SEARCH FOR OIL AND GAS.

KOOTENAI FORMATION.

In this region all the strata so far examined lying between the marine Jurassic beds and the Colorado shale have been placed in the Kootenai formation. Farther south in Montana, however, on the flanks of the Little Belt Mountains and elsewhere, the variegated shales of the Morrison formation have been recognized in the lower part of this interval. The Kootenai formation crops out over a considerable area in the vicinity of Great Falls, on the outer slopes of the Little Rocky Mountains, and on the east end of the Bearpaw Mountains. It has also been penetrated by the drill near Kevin, in Toole County, and in the Sweetgrass Hills district. In the Great Falls area, where the fossil plants characteristic of the formation in the type area in Canada are present, the entire formation can be referred to the Kootenai with considerable certainty. In other areas where outcrops of these rocks have been examined in the mountain uplifts, although the typical fossil plants have not been found, the thickness and general sequence remain much the same. However, the distinctive red color of the shales present along the southern edge of the area mapped becomes less prominent toward the north and northeast.

In the Great Falls district the formation is between 400 and 500 feet thick and is made up of red sandy shale, clay, and gray sandstone, together with a few irregular limestone beds. The red color of the rocks is a prominent feature, the soils on its outcrop being strongly colored. The sandstones range in thickness from 10 to 60 feet, are more or less massive in character, and occur chiefly in the lower half of the formation. They contain a large amount of water.

Near Kevin, in Toole County, as shown by the well log given on page 90, there are beneath the Colorado shale 635 feet of beds that probably belong to the Kootenai. The section there is essentially an alternation of sandstone and shale, but the only red material present is near the top of the formation. There are in this sequence five sandstone beds between 30 and 70 feet thick.

In the Sweetgrass Hills district, as shown by the well log on page 89, there are at least 610 feet of strata containing near the top a prominent bed of red shale that should probably be assigned to the Kootenai. The sandstones at the base are reported to contain gas.

The Kootenai formation is not known to be petroliferous at any point on the outcrop in the areas mapped, although gas is reported from the locality just mentioned. The prominent sandstones in the formation seem to offer excellent reservoirs for either oil or gas if these substances are present at any locality.

COLORADO SHALE.

The formation overlying the Kootenai is the Colorado shale, a great body of bluish-gray to black shale containing in its lower half a number of sandstone beds. This formation, which ranges between 1,500 and 1,750 feet in thickness in north-central Montana, is of marine origin—that is, it was laid down on a sea bottom and contains fossil sea shells in great variety. The rock materials deposited during this marine submergence are continuous northward into Canada and southward across Wyoming and beyond. The interval of time during which they were laid down is called the Colorado epoch, and the rocks themselves when divided into two or more formations constitute the Colorado group.

The Colorado shale seems to be of first importance as a possible source of oil and gas in Montana. The only surface showings of oil so far found in north-central Montana are seeps from the lower part of this formation, and pay sands either in the formation or associated with it have been found in adjoining areas both to the north and to the south of the State. In northern Wyoming the greater part of the oil produced in the Salt Creek field and most of the fields in the Bighorn Basin comes from sands lying mainly in the lower half of this group of rocks. In the Province of Alberta the gas of the important field at Bow Island, east of Lethbridge, is derived from a sand reported to be the Dakota. It is probable, however, that this sand is actually in the lower part of the Colorado shale. Likewise, as reported by Dowling,¹ the small quantity of high-grade oils obtained from several wells in two anticlines lying southeast of Calgary, in the same province, comes from sands at the same position with respect to this shale.

The similarity of the Colorado shale in northern Wyoming and Montana is also emphasized by the presence in both States of a peculiar shale or shaly sandstone carrying abundant impressions of fish scales. In Wyoming this shale, known as the Mowry shale, is about 200 feet thick and occurs in the lower half of the Colorado group. The presence of this fish-scale bed in so many productive oil fields has often been referred to as suggesting that fish remains may have been the source of at least part if not all of the oil found in the associated sands. These peculiar beds are present in at least the east half of the north-central Montana region. In the vicinity of Lewistown, in the central part of Fergus County, a short distance south of the area mapped, a bed about 900 feet above the base of the Colorado shale contains an abundance of fish scales and has been considered² as representative of the Mowry of Wyoming. About

¹ Dowling, D. B., Correlation and geologic structure of Alberta oil fields: *Inst. Min. Eng. Bull.* 102-A, pp. 1360-1364, 1915.

² Calvert, W. R., *Geology of the Lewistown coal field, Mont.*: U. S. Geol. Survey Bull. 390, p. 30, 1909.

75 miles northeast of this locality, on the outer slopes of the Little Rocky Mountains, there are, according to Weed and Pirsson,¹ in a thick shale formation occupying the stratigraphic position of the Colorado shale, some "white porcelaneous beds in which there are abundant impressions of fish scales. This rock weathers into a porcelain-like débris whose light color attracts attention wherever the rocks are exposed." This description is typical of the Mowry throughout large areas in Wyoming. On the east end of the Bearpaw Mountains Bowen² found fish scales in abundance in the Colorado shale, at approximately the same horizon. In the Great Falls area the Mowry was noted by Fisher³ but is not conspicuous. It has not been found elsewhere in the western part of the region here described, although it may be present, the lower part of the formation being poorly exposed and having been little studied.

Sandstone beds, in some places as much as 80 feet or more in thickness, are present in the lower half of the Colorado shale in all parts of central Montana where the formation has been examined along the outcrop or has been pierced by the drill. These sandstones, sealed in by great thicknesses of shale, seem to offer favorable receptacles for the accumulation and retention of oil and gas, and they may contain these substances in commercial quantities where inclination of the strata has permitted their concentration, forming the so-called pools of the oil industry. The sandstone beds in the Colorado shale noted in four widely separated localities in the region are shown graphically in figure 12. The first two of these sections were measured on outcrops of the formation and are taken from reports by Calvert⁴ and Fisher.⁵ The last two are made up from well logs, which are given in detail on pages 90 and 89. The general prevalence of sandstone beds in the lower half of the Colorado shale is evident from this diagram. It is very probable that these sands are more or less lenticular, for the arrangement and thickness of the beds in adjoining areas are such as to make it unlikely that individual sands persist throughout the intervening distances. In general character, thickness, and spacing or distribution in the shale these sandy beds are comparable with those in the Colorado group of the Big-horn Basin oil fields, in northern Wyoming.⁶

¹ Weed, W. H., and Pirsson, L. V., *Geology of the Little Rocky Mountains*: Jour. Geology, vol. 4, p. 409, 1896.

² Bowen, C. F., *The Cleveland coal field, Blaine County, Mont.*: U. S. Geol. Survey Bull. 541, p. 343, 1914.

³ Fisher, C. A., *Geology of the Great Falls coal field, Mont.*: U. S. Geol. Survey Bull. 356, 1909.

⁴ Calvert, W. R., *op. cit.*, p. 30.

⁵ Fisher, C. A., *op. cit.*, pp. 36-37.

⁶ Lupton, C. T., *Oil and gas near Basin, Big Horn County, Wyo.*: U. S. Geol. Survey Bull. 621, pp. 168-173, 1916.

The only noteworthy surface showing of oil so far reported from north-central Montana occurs, according to W. A. English,¹ of the United States Geological Survey, in one of the sandstones of the lower half of the Colorado shale on the north side of West Butte, in the Sweetgrass Hills, a short distance south of the Canadian boundary. Here, in a spring on the Roscoe ranch near the line between secs. 11 and 12, T. 37 N., R. 1 E., there are slight showings of light-greenish oil which collects to the extent of about a teaspoonful in 24 hours. Mr. English also reports that extraction tests made on samples from the sandstone outcrops in the lower part of the Colorado on West Butte give a good show of oil. The petroliferous

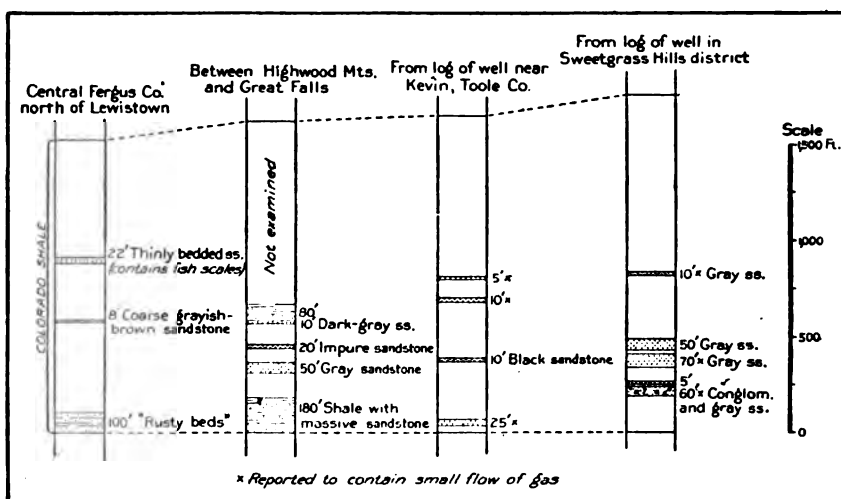


FIGURE 12.—Sections showing sandstones in lower half of Colorado shale, north-central Montana.

nature of the lower part of the Colorado shale in this portion of Montana seems to be clearly demonstrated by this occurrence.

The principal outcrops of the Colorado shale in northern Montana are shown on Plate IV. The largest one is in an extensive area occupying parts of five counties, extending from the vicinity of the Sweetgrass Hills southward to Great Falls. Over most of the interstream areas the shale is hidden under a cover of glacial drift, but along the streams it is generally well exposed.

EAGLE SANDSTONE, INCLUDING VIRGELLE SANDSTONE MEMBER.

Above the Colorado shale throughout north-central Montana there is a group of sandy beds from 250 to 400 feet thick, which constitute the Eagle sandstone. The lower part consists of a persistent

¹ Personal communication.

unit of cliff-making massive sandstone from 100 to 225 feet thick, named the Virgelle sandstone member because of its excellent exposures along Missouri River below the town of Virgelle, in Chouteau County. The Virgelle sandstone is by far the most persistent of the sandstone strata in northern Montana and should serve as an excellent key rock in all drilling operations in the areas under which it is present. Its principal outcrop in the region mapped outlines a broad, oval-shaped area and extends from Missouri River in eastern Chouteau County northward and westward to the Sweetgrass Hills and then turns southward to a point beyond Sun River. (See Pl. IV.) West of the Sweetgrass Hills it forms the prominent escarpment known as "the rim," which extends from these hills southward for about 40 miles. Along the Missouri below Virgelle it forms the features long known as the "stone walls," which extend for about 30 miles along the river.

The strong flow of gas encountered at Havre (see p. 73) comes from the Eagle sandstone. The gas produced at Medicine Hat, in Alberta, is also found at about the same horizon. The porous nature of the Eagle sandstones, together with their position immediately above the Colorado shale, makes it probable that gas and oil in notable quantities are present where the structural conditions are favorable.

FORMATIONS LYING ABOVE PROBABLE OIL AND GAS BEARING BEDS.

Above the probable oil and gas bearing formations there is a considerable thickness of shale, clay, and sandstone, comprising a number of formations of Upper Cretaceous and Tertiary age. They occupy all of the area indicated by the absence of shading on the map (Pl. IV), including nearly half of the region described in this report. East of the one hundred and twelfth meridian they include the Claggett shale, Judith River formation, Bearpaw shale, Lance formation, and Fort Union formation, and their total thickness is between 2,700 and 3,350 feet. West of the one hundred and twelfth meridian they include the Two Medicine formation and the Bearpaw shale, and have a total thickness between 2,350 and 2,650 feet. The thickness and character of the individual formations are given in the tables on pages 53-54.

The thickness of these overlying formations is very important to any one contemplating drilling to the base of the Colorado shale. Drilling from a horizon above the base of the Bearpaw shale to the base of the Colorado will involve depths greater than 3,000 feet. Obviously the addition of a large part of the 2,000 feet or more of the Bearpaw, Lance, and Fort Union formations would make the base of the Colorado far too deep for "wildcatting." The full thick-

ness of the Bearpaw, not over 800 feet, might be added, but areas containing the Lance and Fort Union formations should be avoided. Fortunately, these formations occupy only relatively small areas in Blaine, Fergus, and eastern Chouteau counties. In Chouteau County the Fort Union rocks are present in a small area east of Big Sandy.¹ The Lance, and probably the Fort Union, are present in northern Blaine County in all of the area lying northeast of the Cherry Patch Ridge escarpment. In Fergus County the Lance formation is present along Missouri River east of Dog Creek.

GLACIAL DRIFT.

Glacial drift² of Pleistocene age, consisting chiefly of gravels and boulder clay containing pebbles and boulders of all dimensions, including many of great size, is present over a large part of north-central Montana. It forms an effective cover, concealing the bedrock formations over large areas, and is of more than academic interest to one prospecting for oil and gas in this region. To its presence over so large a proportion of the area may be due the comparative scarcity of oil seeps or gas escapes coming from the underlying bedrock formations in north-central Montana, the compact boulder clay readily concealing any indications that may have been present before it was laid down. The drift also makes it impossible to decipher the structure of the underlying formations over extensive areas lying between the principal streams.

The drift ranges from a thin veneer to deposits several hundred feet thick and is usually thickest in the morainic areas, which have a rough "kettle and knob" topography. All this material was laid down by a continental ice sheet that overrode the region, coming from a center lying west of Hudson Bay. At least two separate invasions of the ice in this region are recorded. The only parts of the plains of north-central Montana that have not been glaciated are (1) the area along Missouri River south of the Bearpaw and Little Rocky mountains and east of R. 15 E., the ice sheet being held back from this area by the topographic barrier formed by these mountains; (2) the area lying west of R. 4 W. in the part of southern Teton County shown on Plate IV.

RECOGNITION OF FORMATIONS IN THE COURSE OF DRILLING.

The general similarity of the rock materials composing the Cretaceous and Tertiary formations of north-central Montana tends to

¹ Bowen, C. F., The Big Sandy coal field, Chouteau County, Mont.: U. S. Geol. Survey Bull. 541, pp. 364-365, 1914.

² Calhoun, F. H. H., The Montana lobe of the Keewatin ice sheet: U. S. Geol. Survey Prof. Paper 50, 1906.

make uncertain the recognition of the various formations encountered in the course of drilling unless certain features are carefully observed. The rocks of the entire section are mainly shale, clay, and sandstone, repeated so many times in the succession of the beds that they are likely to be lumped together in large units of "shale and shells" by the driller.

The principal features on which the recognition of the various formations must depend are (1) differences in the color tone of the various bodies of gray or neutrally tinted rocks; (2) position of the beds of coal or black coaly shale; and (3) position of the thick beds of sandstone. The differences in the color of neutrally tinted shale and clay are the most important and consist of alternations in thick groups of strata of dark-gray, bluish-gray, or nearly black tones with those that are prevailingly light gray, ash gray, or nearly white. These differences are readily distinguished in the course of drilling as the material is poured from the bailer.

In starting at the top of the Judith River formation and going to the Kootenai, the drill will encounter the following succession in the color tones of the gray shale, clay, and sandstone: (1) Judith River formation, light; (2) Claggett shale, dark; (3) Eagle sandstone, light; (4) Colorado shale, dark until the easily recognized "red rock" of the Kootenai is reached. Coals or black coaly shale will generally be found near the top and near the base of the Judith River and at the top of the Virgelle sandstone member of the Eagle. The sandstone beds are apt to be confusing because of the frequent recurrence of beds of various thicknesses, but the general presence of sandy strata over 100 feet thick in the Eagle sandstone should make this formation easily recognizable.

COMPARISON WITH CANADIAN CLASSIFICATION OF FORMATIONS IN SOUTHERN ALBERTA AND SASKATCHEWAN.

The general succession of formations present in northern Montana extends into Canada, where the rocks have been known for many years to the Canadian geologists. The changes in the Montana group, including the disappearance of the Claggett shale toward the west, which first became apparent in studying the section in Montana, are also present and are in every way similar in southern Alberta, where they have been recognized by Dowling.¹

The differences in the formation names used on either side of the Canadian boundary relate chiefly, so far as the probable oil and gas bearing formations are concerned, to the Colorado shale and Eagle

¹ Dowling, D. B., Correlation and geologic structure of Alberta oil fields: *Am. Inst. Min. Eng. Bull.* 102, pp. 1355-1359, 1915. Dowling describes the stratigraphy in Montana but does not refer to the literature previously published on the subject.

sandstone, which the Canadian classification divides into three units—the Dakota sandstone, Benton shale, and Niobrara sands.¹ The “Niobrara sands” are identical with the rocks described as Eagle sandstone in this report. The fact that all fossil evidence is against using the name Niobrara in connection with this sandstone was long ago emphasized by Stanton.² Although in the early days the Dakota was supposed to be present in Montana, it is absent wherever the strata in which it should be present have been examined, and its existence in southern Alberta is believed to be equally uncertain. The sandstone at Bow Island and elsewhere referred to as Dakota by Clapp and others is very probably the sandstone in the lower part of the Colorado shale as described in this report and illustrated in figure 12. The fact that the logs of wells at Bow Island show dark shale beneath the pay sand called “Dakota” is very suggestive of this. Marine fossils found in the basal sandstones of the Colorado shale, described as “rusty beds” in the section from central Fergus County (see fig. 12), seem to prove the marine origin of all these sandstone beds. The use of the name Benton for shale overlying the supposed Dakota in northern Montana is also inadvisable, for no evidence has been found, either paleontologic or lithologic, to warrant recognition of the Benton and Niobrara subdivisions of the Colorado. The simple expedient of applying the term Colorado shale to all these strata in northern Montana has long been in use.

IGNEOUS ROCKS.

Igneous rocks in large areas are present only in the mountain uplifts of north-central Montana, where they occur in laccolithic masses. According to Weed and Pirsson³ the igneous rocks of all these detached mountain groups belong to a single general type of highly differentiated alkaline rocks, usually high in silica. Dikes and sills of these rocks radiate from the mountains, some of them to considerable distances, and cut the Cretaceous beds of the plains. They are especially abundant in a belt from 15 to 20 miles wide between the Highwood and Bearpaw mountains. These dikes and sills have had little effect on the inclosing strata, baking of the beds and displacement having occurred only to a minor extent. They may be of importance in relation to the occurrence of oil and gas, especially where they are abundant, but it is difficult to determine what effect they have had on any hydrocarbons that might be present.

¹ Clapp, F. G., and others, *Petroleum and natural gas resources of Canada*, vol. 2, pp. 265–272, fig. 27, 1915.

² Stanton, T. W., and Hatcher, J. B., *Geology and paleontology of the Judith River beds*: U. S. Geol. Survey Bull. 257, p. 64, 1905.

³ Weed, W. H., and Pirsson, L. V., *Geology of the Little Rocky Mountains*: Jour. Geology, vol. 4, p. 426, 1896.

STRUCTURE.

IMPORTANCE OF STRUCTURE IN THE SEARCH FOR OIL AND GAS.

The lay of the beds in sedimentary rocks is referred to as the structure. If a competent source of supply of oil and gas and a proper receptacle for their accumulation and retention—namely, “sands”—are at hand, structure that permits the concentration of these hydrocarbons into relatively small areas from an originally disseminated condition then becomes of paramount importance in the search for oil and gas. In order to permit the concentration of these substances into commercial pools, it seems necessary that the strata shall have been flexed, tilted, and folded in some manner. It can be said without reservation that oil and gas do not generally accumulate in commercial quantities if the rock layers are perfectly flat. Experience has amply proved the statement of the late Edward Orton that in horizontal beds “you will get a little oil, a little gas, and a little salt water, but not much of anything.”

The structural forms that have proved the most productive are domes or anticlines, produced by upwarps or bulges in the strata. Others of less importance are terraces, monoclines, synclines, and strata bent by faulting. The essential factor is that the beds be tilted or bent, but the degree of tilting varies greatly. In many places it is so slight that it is imperceptible to casual inspection and can not be detected except by close instrumental work, as in the Kansas, Oklahoma, and Texas fields. Elsewhere the tilting may be strongly developed, as in the California and Wyoming fields, where its presence can be ascertained at a glance by a trained observer.

The presence or absence of water in the “sands” is a further qualifying factor in determining the location of pools. The following statements with reference to the presence of water have been proved again and again in developed fields: If the pay sands are saturated with water, the gas and oil, being lighter, will be found above the water in the crests of domes or anticlines or on the flats or terraces of monoclines. If the sands are only partly saturated with water, the gas and oil will be found down on the flanks at the upper level of saturation. If the sands are dry, the oil and gas will have migrated downward to the troughs of the synclines or to a point where further shifting has been prevented. Finally, it is generally although not invariably true that if oil and gas are present in the same stratum, gas, being the lighter, will be found above the oil—that is, farther up on the flanks of the fold.

It is very probable that in Montana large quantities of gas or oil will be found, if at all, only in strongly developed folds, with relatively high dips, such as those in Wyoming, rather than in folds

having very low dips, such as are characteristic of the Mid-Continent fields. This belief is based on the fact that most of the oil fields so far developed in the Cretaceous rocks of the region adjacent to the Rocky Mountains, from Colorado to Alberta, are on strongly developed anticlines. There seem to be no conditions present in Montana which will make that State an exception to the general rule for the Rocky Mountain and Great Plains fields.

STRUCTURE OF NORTH-CENTRAL MONTANA.

GENERAL ASPECT.

Viewed as a whole the structure of north-central Montana is that of a large area of nearly horizontal beds of sedimentary rock that have been intruded by igneous rocks and uplifted in four isolated mountain groups. A general idea of these relations can best be obtained from the section extending entirely across the region through the Bearpaw Mountains, given on Plate IV. On a drawing covering so wide an area the vertical scale is necessarily exaggerated, making the dips in the areas of nearly flat strata appear greater than they really are. Sections made in the same manner, but in different directions, through others of the mountain uplifts, show the same general setting of large areas of nearly horizontal strata intruded and uplifted in the mountains. In relatively small tracts in the areas of nearly horizontal rocks, especially in the region surrounding the Bearpaw Mountains, the beds are much tilted and bent. These upturned beds, however, are nowhere extensive enough to offset the prevailing horizontality of the rocks.

SWEETGRASS ARCH.

The structure of the western half of the region described is characterized by a very broad anticline or arch that extends in a general northerly direction and is here called the Sweetgrass arch. This broad uplift brings the Colorado shale to the surface in an area about 75 miles wide, surrounded on all sides but the south by outcrops of the Virgelle sandstone. (See Pl. IV.) The arch extends southward from the Sweetgrass Hills to the region beyond Teton River, where it flattens out because of the presence of gentle northward dips induced by the uplift of the Belt Mountains, still farther south. On the north this broad uplift extends to and beyond Belly River in Alberta, but it pitches slightly, allowing the overlying rocks of the Montana group to arch over its crest. On the geologic maps of southern Alberta it appears as a broad belt of "Belly River beds," flanked on each side by the overlying marine shale. The Bow Island gas field of southern Alberta lies near the center of this broad arch.

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The location of the axis or crest of a very broad fold of this kind is extremely difficult. In fact, it is not improbable that this arch has no well-defined crest but culminates in an area of slightly undulating, nearly horizontal rocks along its middle part. (See section, Pl. IV.) Most of the arch in northern Montana has not been examined geologically. The possibility of the occurrence of minor folds within the area of the broader arch must be considered, and if any such are present they are important in relation to the occurrence of oil and gas, offering the possibility of getting oil from the Colorado shale at comparatively shallow depths. The oil and gas developments in this area are noted under the local descriptions in this report.

REGION OF TILTED AND FOLDED ROCKS SURROUNDING THE BEARPAW MOUNTAINS.

In the plains surrounding the Bearpaw Mountains for 30 to 40 miles on all sides there are many folds and faults in the nearly horizontal Cretaceous rocks that are irregular in their trend and distribution. The causes of this peculiar and irregular faulting are not well understood, but they are probably related to the extensive igneous intrusions in the Bearpaw Mountains. The faults are all of the thrust type, older formations having been carried upward beside younger rocks that lie for the most part undisturbed. The largest of these faults average about 12 miles in length, but most of them can not be traced more than 4 to 6 miles. The cross section of the Meili fault (Pl. V) illustrates the general type of these faults, although in many of them only the beds on one side of the break are tilted, those on the opposite side remaining undisturbed practically up to the fault plane. The trends of the faults cover all points of the compass, although in small areas a single direction may be dominant—for instance, south of the Bearpaw Mountains many of the faults trend about N. 55° W., while north of these mountains the two principal trends are approximately N. 40° E. and N. 70° W.

These faults have produced in the strata upward arches, which, if the impervious shales overlying the sands have not been broken by the faults, should be as effective reservoirs as anticlines for the storage of gas or oil, or if the impervious cap has been broken the movement along the fault plane has tended to seal the pores in the sand and thus retain any oil or gas that may have accumulated there. The discovery of gas at Havre seems to prove that these faults have not unsealed the underlying sands and suggests that conditions favorable at least for gas and probably for oil are present throughout the wide extent of territory occupied by these faulted structures.

On Plates VI and VII are represented 32 of these faults, including all the principal ones mapped in the areas north and south of the Bearpaw Mountains. Detailed accounts of these areas are given under the local descriptions.

DISTURBED BELT ADJACENT TO THE FRONT RANGE OF THE ROCKY MOUNTAINS.

A small area in the vicinity of the North and South Forks of Sun River, in the southwest corner of the region here described, forms a part of an extensive belt of strongly folded and faulted Cretaceous and Tertiary rocks lying adjacent to the front range of the Rocky Mountains. This disturbed belt extends northward into Alberta, to Calgary and beyond. The discovery of gas and oil in faulted anticlines in this disturbed belt in the vicinity of Calgary has led to considerable excitement in the last few years. Little is known of the details of the part of the disturbed belt lying in the area described in this report, but it is not improbable that anticlines are present there. If so, they are very likely to be much faulted and trend northwest. Where they are underlain by the Colorado shale and Kootenai formation at reasonable depths they offer a probability of obtaining oil and gas with the drill.

LOCAL FEATURES.

AREA OF TILTED AND FAULTED ROCKS NORTH OF THE BEARPAW MOUNTAINS.

HAVRE GAS FIELD.

INTRODUCTION.

The first recorded discovery of gas in the vicinity of Havre was made at Fort Assiniboine by the Quartermaster's Department, United States Army, between June, 1892, and November, 1893, while making a deep boring in the hope of getting artesian water. This well was drilled to a depth of 1,500 feet and obtained a small flow of gas, although no water was encountered below the gravel and sand of the glacial drift. Nothing further was developed until the Havre Natural Gas Co., composed of prominent citizens of Havre, finally obtained a large flow of gas under high pressure 2 miles northeast of the town in July, 1915. The company had previously drilled two wells in Havre, one at the race track and the other at the brewery, at opposite ends of the town. A small flow of gas was obtained in each of these wells, and with commendable persistence the company made a new location, which resulted in the important find just noted. All these locations were made at random, without regard to surface showings of gas or of geologic structure, the guiding principle of those interested being simply the firm conviction

that the gas fields of southern Alberta extended southeastward into Montana.

Acknowledgments are due to Brig. Gen. J. F. Morrison, United States Army, for the well record and information concerning the drilling at Fort Assiniboine, made while he was in command of the post. The writer is also indebted to Dr. J. A. Wright, president of the Havre Natural Gas Co., and to other members of that company for information concerning their operations and for the gas analysis on page 74.

GEOLOGIC FORMATIONS EXPOSED IN THE VICINITY OF HAVRE.

Three of the six Cretaceous formations present in north-central Montana crop out along the Milk River valley in the vicinity of Havre. These are the Claggett shale, the Judith River formation, and the Bearpaw shale. (See table, p. 53.) Because of the thick cover of glacial drift over all the level areas in the region, the exposures of these rocks are limited to the steeper slopes along the stream valleys and coulees. There they are well exposed in freshly eroded badlands, in which the identity of the various units is readily determinable.

The Claggett shale, the oldest formation in this vicinity, is exposed only in the faulted areas lying west of Havre. It consists of soft dark-gray clay shale, about 285 feet thick, characterized throughout by an abundance of the glassy crystals of selenite, a variety of gypsum. The thickness given was obtained in sec. 8, T. 34 N., R. 13 E., where the only complete section of the formation so far found in the Milk River valley is exposed. The shale weathers to a dark gumbo soil that becomes very tenacious when wet. Its most extensive outcrop in the Havre district is in the lower part of Meili Coulee, about 5 miles northwest of Havre, where it is well exposed north of the fault in that vicinity. (See map, Pl. V.)

The Judith River formation is the most extensively exposed formation in the region and crops out in the badlands that extend for many miles along the Milk River valley. It is composed of light-colored clay, clay shale, and sandstone containing lenticular coal beds near the top and a few thin seams at the base. Soft clay beds make up the bulk of the formation, and the rapidity of erosion in these soft strata has produced the extensive badlands. The sandstones are cross-bedded and ripple marked, but in no place are they persistent enough over considerable areas to serve as key rocks. Fossil shells of fresh and brackish water types are present at many horizons. The coal has burned along the outcrop, baking and fusing the overlying beds into prominent brick-red scoria or clinker, a common feature in the badlands of Montana, where coal or lignite beds are present. These "burnt-rock streaks" are clearly due to this

cause, being present only at the coal horizons, and should not be attributed to the burning of oil-bearing shale, as has been maintained by persons interested in the oil prospects of the region.

The best exposures of the Judith River formation in the vicinity of Havre are on the north side of Milk River, where all the coulees leading to the river valley show continuous outcrops of these rocks. The total thickness of the formation in the vicinity of Havre is about 480 feet, according to a measurement made by V. H. Barnett in 1908 across the upturned edges of the formation, the Claggett shale appearing below and Bearpaw shale above, as exposed 3 miles west of Havre, near the mouth of Beaver Creek on the south side of the railway. This is the only exposure known in the Milk River valley, where a complete section of the Judith River beds apparently not disturbed by faulting can be measured.

The Bearpaw shale conformably overlies the Judith River formation. It is a dark gumbo-forming shale, very similar to the Claggett, and is the youngest purely marine formation in northern Montana. It is not distinguishable either by its fossils or by the character of its rocks from the Claggett unless a complete stratigraphic section is present and its position above the Judith River can be definitely determined. In the vicinity of Havre it is exposed only on the south side of Milk River, where it appears in numerous isolated areas, in most of them associated with faults. All these areas are shown on the map (Pl. V). Not more than 350 feet of this shale is present in the area mapped, although the total thickness of the formation is much greater.

Glacial drift covers a large part of the area in the vicinity of Havre, completely obscuring the structure of the underlying Cretaceous formations and therefore greatly increasing the difficulty of prospecting the area for gas and oil. The gravel and boulder clay of this cover of drift are irregular in thickness but in places probably measure over 100 feet. They form the surface of all the areas shown without shading on Plate V. The areas along Milk River and its principal tributaries mapped as occupied by alluvium contain recent stream deposits of sand and silt and a little gravel.

EAGLE SANDSTONE AND COLORADO SHALE.

The Eagle sandstone and Colorado shale are not exposed in the vicinity of Havre, but they underlie most of the area within reasonable drilling depths and seem to offer the best possibilities for obtaining gas and oil. The large flow of gas obtained by the Havre Natural Gas Co. comes from the Eagle sandstone and proves that important quantities of gas are present in that formation. It is noteworthy that the gas at Medicine Hat, about 115 miles northwest of Havre, is produced from sands at the same geologic horizon.

The exposures of the Eagle sandstone nearest to the Havre area lie about 25 miles to the northwest, on Milk River, in T. 34 N., R. 13 E. Here, in the W. $\frac{1}{2}$ sec. 8, the sandstone is brought to the surface in a prominently faulted area, shown on Plate VI. A section across the upturned strata, which strike N. 34° E. and dip 31° SE., is as follows:

Section of Eagle sandstone in W. $\frac{1}{2}$ sec. 8, T. 34 N., R. 13 E.

Claggett shale.	
Eagle sandstone:	Feet.
Sandstone, buff, indurated, with a 6-inch pebble bed near the middle	23
Shale, carbonaceous, brown to black	15
Clay shale, gray, with thin bands of buff sandstone	220
Sandstone, very massive, almost white	30
Sandstone, very massive, light gray, cross-bedded	100
Bottom not exposed.	—
	388

An inspection of the above section shows that the formation is composed essentially of two sandstone members, with a thick shale member between them. The sequence and character of the beds are identical with those of the same formation in the Missouri River section. The thickness, however, is somewhat greater. The 130 feet of massive sandstone at the base of the section corresponds to the Virgelle sandstone member of the Eagle and apparently differs little from that member in the type section on Missouri River, the 30-foot white sandstone being especially like the white sandstone forming "the stone walls" on the Missouri.

The details of the Colorado shale are not known in the vicinity of Havre. The formation has not been drilled through so far as known, but its main features are not likely to be very different from those it exhibits generally in north-central Montana, as described on pages 56-58. The presence of sandstones in the lower half of the Colorado shale, shown in the section on Plate V, is entirely inferential, being assumed from the general prevalence of sandstones in the Colorado in all parts of north-central Montana.

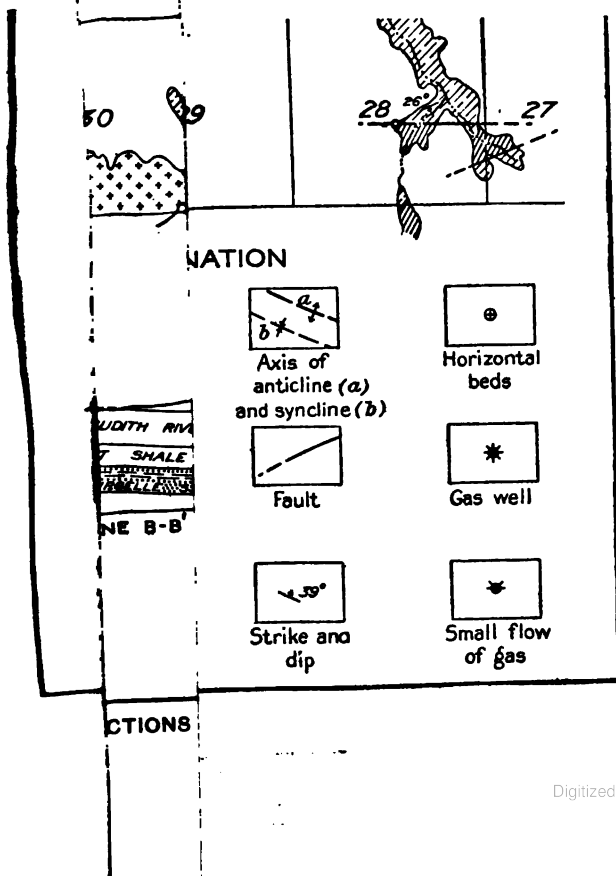
STRUCTURE.

Main features.—The dominant structural feature in the vicinity of Havre is a belt of deformation in which the rocks are folded and faulted, extending about 15 miles in a northwesterly direction across the district. This belt is one of many of similar character and proportions on all sides of the Bearpaw Mountains. The deformation at its southeast end, on Boxelder Creek, seems to have produced two parallel gentle anticlines, here referred to as the Boxelder anticlines. Farther northwest the movement in the rocks appears to have been taken up by several parallel faults that have approximately the same

trend as the anticlines. The most extensive of these is the Meili fault. (See sections on Pl. V.)

Boxelder anticlines.—The extensive exposures of the Judith River formation along Boxelder Creek and the adjoining coulees show two parallel anticlines extending across secs. 8, 9, 16, and 17, T. 32 N., R. 17 E. The outcrops affording the best exposures of the north anticline appear in the coulee that runs northward near the center of sec. 9. On the north side of the anticline dips of 4° NE. are apparent, on the south side the dips are at a maximum of 5° SW. These dips outline a rather narrow-crested fold, trending in a northwesterly direction. The dips outlining the south anticline appear on the east slopes of Boxelder Creek in secs. 8 and 17. In the SW. $\frac{1}{4}$ sec. 8 there is an average dip of 4° NE. in the Judith River beds on the northeast flank of the anticline. On the opposite flank the average dip is about 10° , as is shown in exposures in the SE. $\frac{1}{4}$ sec. 17. The Bearpaw shale is shown in two isolated outcrops surrounded by glacial drift in the S. $\frac{1}{2}$ sec. 17 and seems to come in normally above the Judith River formation. Southwest of these outcrops there are probably some faults parallel with the general trend of the anticlines, for the next rocks exposed to the southwest are the Judith River beds, in such an attitude that the presence of a sharp synclinal fold with an axis lying near the outcrops of the Bearpaw shale does not seem probable. The axes of the two Boxelder anticlines are closely parallel. Their limits on the northwest and southeast are not determinable because of the cover of glacial drift, but they are doubtless parallel to the general trend of the Meili fault, and their extension toward the immediate vicinity of Havre, where the large quantity of gas has been found, is very probable.

Meili fault.—The Meili fault is the principal one of a group of parallel faults trending approximately N. 70° W., northwest of Havre. It can be traced continuously, except for several short covered stretches, for 2 miles, beginning at the edge of the alluvium in the NE. $\frac{1}{4}$ sec. 34, T. 33 N., R. 15 E., and extending to the west line of sec. 28 of the same township. To the southeast, under the cover of the extensive tract of alluvium along Milk River, it may extend a considerable distance parallel with the minor faults that are exposed on the adjacent sides of the Milk River valley. That this fault may extend as far southeast as the center of sec. 5, T. 32 N., R. 16 E., a point about half a mile north of Havre, is suggested by the small exposure of the Claggett shale lying in normal relations beneath the Judith River strata in the NW. $\frac{1}{4}$ sec. 5. This exposure of the Claggett is probably part of a larger tract uptilted by faulting, but now concealed by alluvium, and is comparable with the area of the Claggett shale on the north side of the fault in Meili Coulee.



On the north side of the Meili fault at the place where it crosses Meili Coulee near the south line of sec. 28, T. 33 N., R. 15 E., there is a large area of the Claggett shale faulted in part against the Judith River beds and in part against the Bearpaw shale. The maximum stratigraphic displacement along this fault is about 800 feet. The dips in the area of the Claggett shale along Meili Coulee are all northeastward. They average about 5° near the fault, but farther north, near the middle of sec. 28, they become steeper, an observed dip of 16° being noted, and still farther north, about $1\frac{1}{2}$ miles from the fault, the dip has flattened to 1° . The structure thus shown is in effect that of a broad anticline which has been cut on the south by the Meili fault. (See section A-A', Pl. V.) South of the Meili fault, at the same locality, the dips are also to the north, averaging as high as 40° , but a short distance to the southwest they reverse, making a sharp anticline, beyond which the beds assume a horizontal position.

West of sec. 28 the Meili fault may be continuous, though it changes slightly in trend, to a direction more nearly west, with the fault that crosses the coulee near the center of sec. 29, which also brings the Claggett shale into contact with the Judith River formation. A quarter of a mile north of the latter fault is a closely folded anticline that follows the trend of the Meili fault and extends northwestward as far as Supenau Coulee, a distance of over 3 miles. This fold is much covered by glacial drift between the coulees, but the close alignment of all the exposed parts makes their unity very probable. The dips on either flank of this anticline are steep but irregular, ranging from 18° to 75° on the north side of the fold and from 13° to 38° on the south side.

Minor faults near Havre.—Two faults paralleling the Meili fault and extending through secs. 35 and 36, T. 33 N., R. 15 E. (see Pl. V), have a much smaller throw than the Meili fault and do not at any point bring the Claggett shale to the surface. As in the Meili fault, the dips on the north side of these breaks are northward, away from the faults, and the degree of tilting is similar to that along Meili Coulee.

West of Havre, just south of the railway, faulted beds are exposed across secs. 1 and 6 in steeply tilted blocks which are visible from the west end of the town. The formations involved include the Claggett, Judith River, and Bearpaw. The trend of the faults and the strike of the beds in this disturbed area are all apparently parallel to the trend of the Meili fault. The beds north of the northern fault dip between 30° and 45° S. The tilted block north of this fault, if the strike continues, extends beneath Havre under the area covered by alluvium. This fact makes it probable that the

gas well near the brewery at the west end of the town is located in tilted beds, and there is also some likelihood that the well at the east end of the town is in the same tilted block. South of the fault just mentioned the beds tilt northward, so that the structure here is in effect that of a syncline, broken along its axis by a fault.

GAS DEVELOPMENTS.

The gas in the well at Fort Assiniboine was encountered at a depth of about 1,200 feet.¹ The pressure was not great. The gas burned freely when lighted, but the flow lasted only a few days. It is probable that the bed yielding this gas was in the Eagle sandstone. The rocks penetrated in this well are shown in the following log:

Log of well drilled by the Quartermaster's Department, United States Army, at Fort Assiniboine, Mont., between June, 1892, and November, 1893.

[Altitude of surface, about 2,660 feet.]

Probable formation.	Driller's description of the rock.	Thick- ness.	Depth.
Glacial drift.	Clay, gravel, and sand	<i>Fet.</i> 65	<i>Fet.</i> 65
Bearpaw shale.	Soft gray slate rock	375	440
Judith River formation.	Black shale, with small portion of coal mixed	30	470
	Gray fire clay, slate, and soapstone mixed	108	578
	Shale, white and black clay mixed	312	890
Claggett shale and Eagle sandstone.	Slate, soapstone, and chalk mixed	170	1,060
	Soapstone, very soft, porous, and full of seams	440	1,500

The bedrock formations over a large area in the vicinity of the well are concealed by glacial drift, and therefore there is some uncertainty as to the formations pierced by the drill. The 375 feet of "soft gray slate rock" lying immediately below the gravel and sand of the glacial drift is very likely the Bearpaw shale. This is made fairly certain by the presence of the 30-foot member described as "black shale, with small portion of coal mixed," which, overlying a considerable thickness of gray rocks, is very likely the coal zone at the top of the Judith River formation. With these two formations determined the remainder of the log would follow in sequence as indicated above, unless the strata are much disturbed. The considerable thickness of material at the bottom of the well described as "soapstone, very soft, porous" very likely absorbed the drilling

¹ Personal communication from Brig. Gen. J. F. Morrison, U. S. Army.

water rapidly and, it seems probable, is the sandstone of the Eagle. True soapstone could not be described as porous and would not take up the drilling water.

The well at the west end of Havre, near the brewery, was drilled to a depth of 1,370 feet. Gas was obtained at 900 feet and again at the bottom of the hole, but each flow was small. The gas at the bottom of the hole gave a closed pressure of 540 pounds after 36 hours. The well at the east end of Havre, at the race track, is 1,285 feet deep. It yielded some gas at 885 feet and a larger flow at the bottom, which was estimated to be less than 1,000,000 feet a day. The gas from the lower sand gave a maximum closed pressure of 540 pounds in 24 hours.

The principal gas well of the Havre Natural Gas Co., brought in early in July, 1915, is in the SE. $\frac{1}{4}$ sec. 33, T. 33 N., R. 16 E., about 2 miles northeast of Havre, just south of the Great Northern Railway. This well is on a low terrace overlooking Milk River, in a large area in which the bedrock formations are concealed either by the alluvium along the river or by the glacial drift on the higher slopes, making it impossible to decipher the rock structure in the immediate vicinity of the well. However, as indicated by the surrounding exposures, it is very probable that the Judith River formation immediately underlies the glacial drift in most of this area. This well is 947 feet deep and at the bottom obtained a large flow of gas which was roughly estimated, by taking minute pressure readings, to amount to 10,000,000 feet in 24 hours. This method of obtaining the open-flow volume of a gas well is unreliable, and the figures are therefore only approximate. The initial closed pressure of this well in July, 1915, was about 490 pounds to the square inch. No later readings have been obtained.

The rocks encountered in drilling this well were described to the writer in a general way by Dr. Wright, of the Havre Natural Gas Co. There seems to be little reason to doubt that the drill went through part of the Judith River formation, all of the Claggett, and part of the Eagle sandstone. The estimated stratigraphic position of the first rocks encountered below the glacial drift is about 400 feet above the base of the Judith River formation. If the thickness of the Claggett shale is taken as 285 feet and that of the Eagle sandstone as 390 feet, the bottom of the hole is about 100 feet from the base of the Eagle sandstone and hence is probably in the Virgelle sandstone member of the Eagle.

An analysis of the gas from this "gusher" well was kindly furnished by the Havre Natural Gas Co. and is given below, together with one of gas from Alberta for comparison.

Analyses of natural gas from Havre, Mont., and Medicine Hat, Alberta.

[Analysts not known.]

	Havre.	Medicine Hat. ^c
Carbon monoxide (CO).....	0.20	.....
Methane (CH ₄).....	94.80	99.49
Nitrogen (N).....	5.00	.....
Hydrogen sulphide (H ₂ S).....	.....	.51
	100.00	100.00
Heating value per cubic foot (British thermal units).....	897	.....

^c Clapp, F. G., and others, op. cit., vol. 1, Table 12.

The analysis in the first column is that of a "dry" gas from which little or no gasoline could be extracted by freezing tests and which is very similar to that obtained at Medicine Hat, being composed chiefly of methane and not containing any of the higher series of hydrocarbons. The heating value given is too low for that of a natural gas containing 95 per cent of methane, and therefore there may be an error either in the determination of heating value or in the analysis. A recent analysis of this gas by G. A. Burrell, of the Bureau of Mines, gave the following: Heating value, 1,036 British thermal units; methane, 97.3 per cent; nitrogen, 2.7 per cent.

A comparison of the results of this large gas well with those of the wells drilled at Medicine Hat is of interest because the gas obtained at the two localities comes from the same geologic formation. At Medicine Hat, in December, 1913, there were 16 municipal wells between 1,000 and 1,300 feet deep, having an open-flow capacity of 43,200,000 cubic feet a day, according to a statement by the city engineer. The production of the largest of these wells from a 10-inch aperture was 6,000,000 feet a day, but the average yield is between 2,000,000 and 3,000,000 feet. There are also in this field several wells, owned by manufacturing companies, concerning which data are not available. The development of these gas resources has led to a rapid industrial expansion at Medicine Hat.

PROBABLE EXTENSION OF THE FIELD.

The gas pool in the district about Havre will probably have its greatest extension in a direction S. 70°-75° E. This statement can be made with considerable certainty, because (1) the single dominant uplift in the district has this trend, and (2) the strong flow of gas encountered is with little doubt located on or near this uplift. If this strong flow should prove to be short-lived the location is probably too far down the flank of the inclined strata present. The territory along the axes of the two Boxelder anticlines and along the probable extension of these axes, especially northwestward toward

Havre, seems to offer the best chance for further extension of the field. On the north side of the Meili fault the area of tilted beds occupying parts of secs. 27, 28, and 34, T. 33 N., R. 15 E., seems to be favorable, with a chance of getting gas at comparatively shallow depths. There is also a probability of getting oil and gas in these areas by drilling for sands in the lower part of the Colorado shale at depths of 2,000 to 3,000 feet, the depth depending on the location on the folds.

EXTENT TO WHICH FAULTS HAVE PERMITTED THE ESCAPE OF GAS OR OIL.

The extent to which faults have unsealed any deep-seated sands containing gas or oil and have therefore allowed much of their contents to waste is an important problem in the Havre district and in all of the area surrounding the Bearpaw Mountains where faults are generally prevalent. All the evidence at hand seems to indicate that in the soft Cretaceous formations of the Rocky Mountains and the Great Plains faulting can at the most only slightly unseal the underlying sands. This seems to be especially true of the sands in a thick mass of soft marine shale, such as the Colorado shale. In Wyoming this is shown by the fact that many of the producing anticlines are faulted, some of them to a considerable extent. In the Calgary region, Alberta, a 2,000,000-foot flow of gas obtained from an area of much faulted rocks in the disturbed belt¹ adjacent to the Rocky Mountains is further proof that gas can accumulate in faulted rocks, if the formations are composed of soft materials. The well at the west end of Havre, at location No. 2, seems to offer proof of this also, for although it is situated close to two faults of considerable throw, it contains gas which had an initial closed pressure of 540 pounds to the square inch.

CHANCES OF SUCCESS BY RANDOM DRILLING IN THE MILK RIVER VALLEY.

A successful oil or gas well invariably leads to a popular belief that the hydrocarbons are to be found under all lands in the district in which it is situated, and that drilling at random locations in that district is certain to be successful. In the Milk River valley, throughout which the geologic features remain much the same, five deep borings have been put down at random locations—three at Havre, one at Chinook, and one at Fort Assiniboine. Only one of the five was successful, and there is no reason to believe that drilling at haphazard locations will be any more successful over the remainder of the area. The only possibility of decreasing this percentage of dry holes outside of the proved territory is by a better understanding of

¹ Clapp, F. G., and others, op. cit., vol. 2, p. 283.

the lay of the rock strata and its influence on the accumulation of oil and gas.

OTHER AREAS OF TILTED AND FOLDED ROCKS NORTH OF THE BEARPAW MOUNTAINS.

Areas of tilted and folded rocks in the region north of the Bearpaw Mountains are shown on Plate VI. Structure similar to that at Havre has been noted in at least 11 widely scattered localities. In much of the area lying between these faulted tracts the hard rocks are covered by glacial till and their structure is therefore not known, but it is possible that other anticlines or tilted blocks as extensive as those represented on the map are present in the region. However, large areas are certainly underlain by rocks that are nearly or quite horizontal. Outside of the Havre district no developments of oil or gas or even indications of these substances have been found in the area shown on Plate VI. In the following pages the principal features of these areas of tilted beds will be described, beginning with the northernmost tier of townships and progressing southward.

T. 37 N., R. 15 E.

On Signal Butte, in the west half of T. 37 N., R. 15 E., an anticline, broken along its crest by faulting, extends in a direction approximately N. 25° W. This anticline can be traced very clearly for about 2 miles, and there is a possibility that it extends for several miles more under the glacial drift. The exposures on the east side of Signal Butte are excellent. They show the Judith River formation with its coal zone lying near the top, together with 200 feet of the underlying beds. The Bearpaw shale appears normally above the Judith River formation on either flank of the broken fold. The structure is clearly anticlinal—that is, the beds dip away on both sides from a middle axial line, although there is some displacement by faulting along this axis. On the northeast side of the anticline the dips close to the fault line range from 10° to 32°. Toward the east they flatten rapidly, and about a mile from the fault the strata lie nearly horizontal. On the west side the beds do not dip so steeply, the average dip being not over 12°, except in a few irregularly disturbed tracts. In the S. $\frac{1}{2}$ sec. 20, on the fault cutting the crest of the anticline, there is a spring whose surface is covered with a thick film of reddish-brown ferric hydroxide. This material should not be mistaken for oil. No signs of oil or gas were found in the vicinity. A cross fault in the S. $\frac{1}{2}$ secs. 19 and 20, nearly at right angles to the trend of the broken anticline, forms the south boundary of a block of Judith River beds which are tilted to the northeast at angles of 6° to 13°. This tilted block lies in anomalous relations to

the faulted anticline just described and covers an area of nearly 4 square miles.

T. 36 N., R. 14 E.

In the east half of T. 36 N., R. 14 E., mainly in secs. 11, 14, 22, and 23, there is a tilted block of rocks having an average dip of about 8° , bounded on the northwest side by a fault. On the whole the exposures in this vicinity are not good, the limits of the tilting being hidden either by glacial drift or alluvium. The best exposures appear on the northward-facing slope in the N. $\frac{1}{2}$ sec. 23. Practically all of the Judith River formation is exposed along this slope, and there is probably a little Claggett shale at its west end. The dips for the greater part of the distance average between 7° and 8° . Near the top of the Judith River there is a local dip of 28° , but this flattens to about 9° a short distance farther southeast. The Bearpaw shale appears on this slope in normal relations above the Judith River beds and is exposed to the southeast across almost all of sec. 24. The actual extent of this tilted block can not be determined, but to judge from the area of the exposed portion it seems safe to say that, as indicated on the map, it extends at least 2 miles in a northeasterly direction.

T. 35 N., R. 12 E.

In the west half of T. 35 N., R. 12 E., the rocks are uplifted and tilted to the southeast by a fault that has a general trend of N. 25° W., and extends from Milk River near the southeast corner of sec. 14 northwestward for at least 4 miles, crossing secs. 6 and 7 of the township adjoining on the east. On the northwest side of the fault the area is occupied by the Judith River formation, which lies approximately horizontal for many miles to the northwest, and the beds are undisturbed, even in close proximity to the fault plane. On the southeast side the beds are tilted to the southeast in an area occupying 4 to 5 square miles. The Claggett shale is the lowest formation exposed in this area and crops out in a belt that averages a quarter of a mile in width adjacent to the fault and is traceable as far as the fault is exposed. Southeast of the Claggett outcrop is the lower part of the Judith River formation, with a persistent thin coal bed at the base in normal relations to the Claggett shale. The highest dip (60°) in this tilted block was observed in the Claggett shale in sec. 14. The average dip is not over 40° . Northeast of this area, in secs. 12, 6, and 7, the dips in the Claggett shale at the same position with reference to the fault do not average more than 20° to 25° . In sec. 14 the beds are approximately horizontal within three-fourths of a mile of the fault. Farther north the distance from the fault to practically horizontal beds is somewhat greater, but nowhere is it more than 1 mile.

T. 35 N., R. 14 E.

On the upper end of Red Rock Coulee, in T. 35 N., R. 14 E., there is a tilted block of strata between two parallel faults extending for 4 miles in a northeasterly direction. The areas northwest and southeast of the two faults bounding this block are underlain by the Bearpaw and Judith River formations, for the most part nearly horizontal. Between the faults the rocks are considerably tilted, and the steepest dips are on the southeast edge of the block, where dips in the Bearpaw shale and in the coal zone in the upper part of the Judith River formation range from 35° to 70° . On the northwest edge of the block the dips are much less, the observed readings varying from 6° to 14° . The lowest rocks (the upper part of the Claggett shale) are exposed in sec. 30. Southeast of this point the full thickness of the Judith River beds is present, followed in the SW. $\frac{1}{4}$ sec. 29 by a small amount of the Bearpaw shale.

T. 35 N., R. 16 E.

In T. 35 N., R. 16 E., near the head of a small coulee tributary to Red Rock Coulee, there is an area of tilted beds that strike about N. 65° E. These beds dip to the southeast at an average angle of about 20° , although readings as high as 37° were observed. The lowest beds exposed are those of the Claggett shale, which are followed in normal sequence by the Judith River formation with its coal zone at the top, which is well exposed. Southeast of the coal outcrops, near the south side of sec. 14, the Judith River beds are folded into a shallow syncline that lies on the south edge of the tilted block. Beyond this syncline the area is entirely covered with glacial drift. The extent of this tilted block in the direction of the strike is very uncertain because of the general cover of glacial drift, which makes it impossible to follow the exposures beyond the sides of the coulee.

T. 34 N., R. 12 E.

In the northeastern part of T. 34 N., R. 12 E., on Milk River, there is a fault trending about N. 55° E., which is exposed on both sides of the river valley and extends an unknown distance under the drift to the northeast and southwest. Northwest of this fault, up Milk River, the only formation outcropping for many miles is the Judith River, which lies nearly horizontal even in close proximity to the fault plane. Southeast of the fault for a distance of over a mile the strata are tilted to the southeast. The Claggett shale is the oldest formation exposed on this side, and overlying it are the Judith River beds in normal sequence, with a thin coal bed near their base. Within 1,500 feet of the fault the observed dips range from 35° to

60°. Farther away the dips flatten rapidly to 10° and then gradually lessen until the strata are nearly horizontal. The exposed rocks involved in this tilting occupy an area of about 3 square miles, but the total area may be much greater, including extensions under the cover of glacial drift.

T. 34 N., R. 13 E.

In T. 34 N., R. 13 E., there are three tilted blocks identical in form and nearly parallel to those in the adjoining townships to the west and the northwest, already described. Each block is separated by a fault trending northeast from a considerable area of nearly horizontal rocks on the northwest. The northernmost of these tilted blocks cuts across Saddle Butte, extending from secs. 18 and 19 to secs. 4 and 5. Practically all of the Eagle sandstone is brought up by the faulting. This occurrence is noteworthy, as it is the only outcrop of the Eagle formation in this part of the Milk River valley. The Eagle is the lowest geologic formation exposed in the area covered by Plate VI, and the section given on page 69 was measured at this point. The full thickness of the Claggett shale and the lower part of the Judith River formation, with a thin coal bed near the base, are also exposed. The dips in the zone occupied by the Eagle and Claggett in this faulted area in the first quarter of a mile southeast of the fault vary from 45° to 15°. Beyond this they rapidly become less, and a mile from the fault the beds lie nearly horizontal.

About 3½ miles southeast of the fault just described there is a similar fault crossing the Milk River valley and extending from the W. ½ sec. 22 northwestward as far as sec. 1, a distance of a little over 3 miles. The extent of this fault beneath the glacial drift beyond these limits can not be determined. According to Pepperberg,¹ the Claggett shale is the lowest formation brought to the surface in this faulted uplift. The beds on the northwest side of the fault are nearly or quite horizontal for several miles to the northwest. On the southeast side the dips appear to be irregular, varying from 14° to 60°. Farther southeast the beds flatten to a nearly horizontal position within a mile of the fault.

Farther down the Milk River valley the Judith River formation, lying nearly horizontal, is exposed on both sides of the valley as far as the center of sec. 36 and is the only formation exposed in this territory. Half a mile above Brown's ranch there is an anticline, broken to some extent by faulting, here referred to as the Browns Coulee anticline. This anticline trends in a northeasterly direction and extends several miles into the township adjoining on the east. An account of it is given under the next heading.

¹ Unpublished data.

T. 34 N., R. 14 E.

From the west bank of Milk River, in sec. 36, T. 34 N., R. 13 E., the Browns Coulee anticline is well exposed, with minor interruptions, for a distance of about 3 miles, as far as the east side of Browns Coulee, in sec. 32, T. 34 N., R. 14 E. How much farther northeast and southwest it extends under the drift-covered prairies is not known. Beginning on Milk River in the southeast corner of sec. 36, its axis trends N. 65° E., passing a few rods south of the east quarter corner of the section. Continuing northeastward it crosses the north branch of Browns Coulee about 700 feet north of the center of sec. 31. In the main branch of Browns Coulee, in the NW. $\frac{1}{4}$ sec. 32, the crest of this fold is broken by a fault of relatively small throw, the dark shale of the Claggett abutting against a massive brown sandstone at the base of the Judith River formation, but the essential anticlinal nature of the structure, the strata dipping in opposite directions from a medial line, still prevails. The Claggett shale, according to Pepperberg,¹ is the lowest geologic formation exposed on the Browns Coulee anticline. The observed dips on the north limb of the fold range from 20° to 55° within half a mile of the axis; on the south limb the recorded dips range from 10° to 50°. The north limb is somewhat the more steeply tilted of the two. The total distance in a direction transverse to the axis of this anticline between the beds lying nearly horizontal on the north and those in the same attitude on the south is about 1 $\frac{1}{2}$ miles.

TILTED AND FOLDED ROCKS NORTH OF CHINOOK.

T. 34 N., R. 19 E.

On Lodge Creek, in the southwestern part of T. 34 N., R. 19 E., the Claggett and Judith River formations are tilted about 25° S. in an area covering parts of secs. 19, 20, 29, and 30 and probably extending a short distance into the township adjoining on the west. The fault that produced this tilting crosses the river valley near the south quarter corner of sec. 19 and trends N. 17° E. There are no exposures on Battle Creek, where this fault, if extended, would cross the valley. The prevailing cover of till and glacial drift makes it impossible to determine how far the tilting continues.

In the southeastern part of this township there is an anticline whose axis trends northwest. It is very poorly exposed and seems to merge into a fault, which becomes prominent in the township to the south. The most definite indications of this fold are in the vicinity of the southwest corner of sec. 23, where the axis trends N. 30° W. and is outlined by opposite dips appearing on both sides of the valley of Dry Fork Creek. The fold is probably closely compressed. The observed dips on the east limb range from 20° to 75°

¹ Unpublished data.

and those on the west limb from 4° to 30° . In the S. $\frac{1}{4}$ sec. 35 there is a fault in the position that would be occupied by the anticlinal fold above mentioned if it were extended. This fault, however, trends more nearly north and causes the Judith River beds, dipping 11° W., to abut against the Bearpaw shale.

T. 33 N., R. 19 E.

On Battle Creek, in the northeastern part of T. 33 N., R. 19 E., there is a fault trending nearly north, which seems to merge into the axes of the small anticlines at each end of it. For the greater part of the distance along this fault the Judith River formation, which is the lowest geologic formation exposed, abuts against the Bearpaw shale, the Judith River beds appearing mainly on the west side of the fault and the Bearpaw shale on the east. The dips within a few hundred feet on either side of the fault appear to be very steep, the observed readings, according to Pepperberg,¹ being as high as 65° , but the dips lessen both east and west of the fault line, and at a distance of one-half to three-fourths of a mile the beds lie approximately horizontal. On the east side of the fault the beds dip to the east at angles between 60° and 3° , according to the distance from the fault line, making the structure in effect anticlinal—that is, the beds dip in opposite directions from a medial line.

The only drilling operation in this part of the Milk River valley whose record is available was undertaken at Chinook in July, 1890. The well was drilled to a depth of 960 feet² by the town of Chinook in an attempt to develop artesian water. At the bottom of the bore, in a 6-foot stratum of blue clay, gas and petroleum were reported. Water was encountered at several horizons, of which the lowest, at 540 and 620 feet, yielded salt water. The log of this well is as follows:

Log of well at Chinook, Mont.

[Elevation, 2,404 feet.]

Probable formation.	Driller's description of the rock.	Contents.	Thick- ness.	Depth.
Glacial drift.	Loam and sand.....	Water.....	<i>Feet.</i> 112	<i>Feet.</i> 112
	Stone boulders.....		12	124
Chaggett shale or Colorado shale (?).	Stiff clay.....	Water.....	96	220
	Sandstone.....		2	222
	Blue clay.....	Salt water...	218	540
	Sandstone.....		14	544
	Blue clay.....	Salt water...	784	620
	Blue clay, interspersed with thin strata of lime and sandstone, soft mud.		330	950
	Blue clay.....	Gas and pe- troleum.	6	956

¹ Unpublished data.

² Nettleton, E. S., Final report on artesian and underflow investigation to the Secretary of Agriculture: 52d Cong., 1st sess., S. Ex. Doc. 41, pt. 2, pp. 72-73, 1892.

T. 23 N., R. 20 E.

On Coal Creek, in the west half of T. 23 N., R. 20 E., there is a fault whose trace makes a curved outline that can be followed, except for several minor interruptions by drift and alluvium, for about 3 miles across secs. 3, 10, and 14. According to Pepperberg,¹ the Bearpaw shale is present over most of the northern part of this township, but the Judith River formation, the lowest exposed, is brought to the surface along the southwest side of the fault. The observed dips in these beds, which are tilted to the southwest, range from 3° to 20°. The exposures are poor, and the distance to which the tilting of the strata extends southwestward was not determined, but it is probably as much as three-fourths of a mile.

AREA OF TILTED AND FOLDED ROCKS SOUTH OF THE BEARPAW MOUNTAINS.

GENERAL FEATURES.

In the vicinity of Missouri River south of the Bearpaw Mountains there are many areas of tilted and folded rocks similar to those near Havre, already described. On Plate VII the largest and least disturbed of these areas of folded and faulted rocks, comprising 18 separate structural features, each of which may be of importance as a reservoir of oil and gas, are outlined. A considerable portion of the area lying north of Missouri River has not been examined geologically, but there are doubtless similar structural features in these unsurveyed townships. Escapes of gas or seeps of oil have not been recorded in any part of the region along Missouri River, nor are the records of any deep borings available.

FAULTED AREAS IN THE VICINITY OF VIRGELLE.

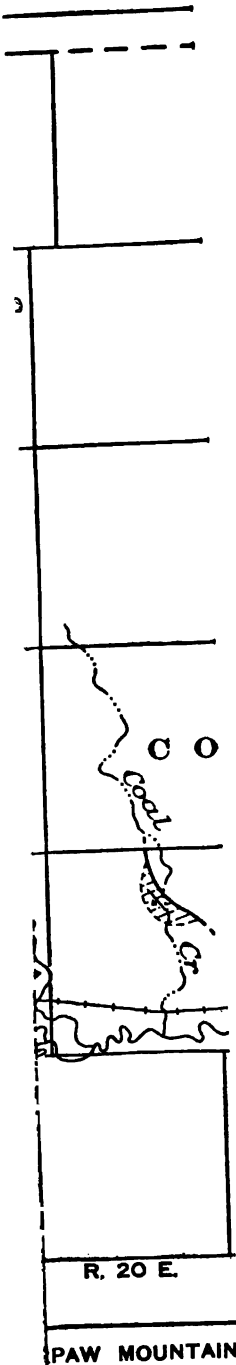
In T. 26 N., Rs. 11 to 13 E., in the vicinity of Virgelle, there are four areas of tilted rocks in which the Colorado shale is the lowest formation exposed. The westernmost of these tilted blocks is produced by a fault that crosses secs. 16, 17, and 18, T. 26 N., R. 11 E., extending from the west side of Missouri River along the coulee that enters the river near the center of sec. 16. This fault, according to E. R. Lloyd,¹ trends N. 65° W., and is best exposed along the sides of the coulee in secs. 17 and 18. The Colorado shale is exposed southwest of the fault, where it dips to the southwest at low angles for half a mile to a mile beyond the fault line. On the fault line the lower shales of the Colorado have been carried upward against the Virgelle sandstone and the uppermost beds of the Colorado. The beds on the northeast side of the fault lie for the most part nearly

¹ Unpublished data.

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horizontal. A second fault, nearly parallel with this one, and the largest of those present in the vicinity of Virgelle, extends from a point near the center of sec. 20, T. 26 N., R. 12 E., northwestward to a point near the south quarter corner of sec. 4, T. 26 N., R. 11 E., a distance of about 6 miles. This fault is well exposed in sec. 24 of the latter township, on the south bank of the Missouri. Here beds of the Colorado shale that dip as much as 43° abut against nearly horizontal beds of the Colorado shale, but the inclined beds flatten to nearly horizontal within about three-fourths of a mile. To the northwest the trend of this fault follows Missouri River very closely, but the fault is covered by the alluvium along that stream as far as the W. $\frac{1}{2}$ sec. 10. From sec. 10 to its northeastern extremity the fault is again well exposed and has a trend identical with that noted in sec. 24. A tilted block on the southwest, composed of Colorado shale, abuts against nearly horizontal Virgelle sandstone and the upper beds of the Colorado shale on the northeast. This fault can be traced for about 2 miles, into the township on the east, to a point where it is concealed under the cover of glacial drift. The trend changes to nearly east, as shown by the exposures near the center of sec. 20, T. 26 N., R. 12 E.

In the north half of T. 26 N., R. 12 E., about 4 miles northwest of Virgelle, tilted rocks lie on the west side of a fault trending N. 40° E., which crosses Missouri River in the W. $\frac{1}{2}$ sec. 3 and extends northeastward beyond the river for a short distance to a point where it is concealed by glacial drift. The dips near this fault are comparatively steep, but they flatten rapidly, and within a mile of the fault plane the beds lie horizontal.

The fourth area of tilted rock in the vicinity of Virgelle occupies a part of the west half of T. 26 N., R. 13 E., near the lower end of Lone Tree Coulee. The fault, which has uptilted the beds in this locality, trends nearly west across secs. 17 and 18 of this township and is cut at several points by dikes of igneous rock. On the north side of the fault the beds are tilted northward at angles ranging from 23° to 60° , the steeper dips being near the fault, and the area of tilted rocks extends about a mile from the fault line. The Colorado shale, the lowest formation exposed, is overlain by the Eagle sandstone and Claggett shale in normal succession. On the south side of the fault the beds lie nearly horizontal, except in the S. $\frac{1}{2}$ sec. 17, where exposures in the Claggett shale on Lone Tree Coulee show a small anticline with dips of 3° on the west limb and 4° on the east and an axial trend approximately due north. This anticlinal axis probably meets the fault mentioned above near the center of sec. 17. Its southward extent is not known because of the prevailing cover of glacial drift.

FAULTED AREAS ALONG MISSOURI RIVER BETWEEN EAGLE CREEK AND ARROW RIVER.

In the west half of T. 25 N., R. 13 E., and in the township adjoining on the south, there are two nearly parallel faults trending about N. 30° W. The northern fault can be traced continuously, except for several interruptions caused by the cover of glacial drift, from sec. 7 to the west bank of the Missouri in sec. 28. The tilted beds, which occupy an area extending about three-fourths of a mile southeastward from the fault line, show dips that for the whole area may average about 15°. The Colorado shale is the lowest geologic formation exposed and is overlain in normal succession to the southwest by the Eagle sandstone and the Claggett formation. The second of the two faults in this township crosses the NE. $\frac{1}{4}$ sec. 31 in a direction about N. 50° W. As in the faulted rocks lying immediately to the north, the Colorado shale is the lowest formation exposed in the tilted block southwest of this fault. The fault reaches the west bank of the Missouri in the NE. $\frac{1}{4}$ sec. 4, T. 24 N., R. 13 E., where it finally disappears under the alluvium on the sides of the river. Its extent southeastward along the opposite side of the river is not known, that area not having been examined, but the trend of the fault is so closely in alignment with that of the extensive fault crossing the west half of T. 23 N., R. 14 E., that they are probably parts of a single fault.

In the west half of T. 25 N., R. 14 E., there is an area of strata tilted to the northeast along a fault mapped by Bowen,¹ trending about N. 50° W. These upturned rocks occur in a large area in which the Claggett shale is the principal formation. The Eagle sandstone, the lowest formation exposed, has been carried upward and lodged against the Claggett shale lying southwest of the fault. This fault is in many places concealed by the usual cover of glacial drift, but the best exposures are on Spring Creek in secs. 19 and 29. Where this fault crosses Eagle Creek, near the southwest corner of sec. 18, it turns to a direction N. 20° W. The area occupied by the tilted strata, so far as the exposures indicate, includes about 4 square miles.

In the west half of T. 23 N., R. 14 E., and the townships adjacent on the northwest, west, and south, there is a fault over 12 miles long. In places this fault produces an anticline, as the dips are in opposite directions on the two sides of the fault line. Most of the tilted beds, however, lie on the southwest side of the fault. The rocks affected by this long and somewhat irregular fault show at a number of points where it crosses the watercourses. The northwest end of the fault is best exposed where it crosses Missouri River, in the

¹ U. S. Geol. Survey Bull. 541, pl. 21, 1914.

S. $\frac{1}{2}$ sec. 25, T. 24 N., R. 13 E. Here an area of tilted Colorado shale overlain by the Eagle and Claggett formations is exposed southwest of the fault, which trends S. 30° E. It next appears, with approximately the same trend, along the watercourses in the W. $\frac{1}{2}$ sec. 1, T. 23 N., R. 13 E., where the Colorado shale dips both to the southeast and the southwest from the fault line. From this locality the beds are covered by glacial drift as far as the crossing of the next coulee, in the W. $\frac{1}{2}$ sec. 7, T. 23 N., R. 14 E. In the coulee at this point the Colorado shale and the entire succession of formations above it are again well exposed. Farther southeast the fault, trending about S. 20° E., is still readily traceable by means of the numerous exposures in the drainage ways to the south side of T. 23 N., R. 14 E., crossing Flat Creek Pass in the N. $\frac{1}{2}$ sec. 33. It continues southwestward as far as sec. 15, T. 22 N., R. 14 E., crossing the main valley of Flat Creek in sec. 10. At this point there is a considerable area of tilted rocks on the southwest side of the fault, and the average dip in the more steeply tilted beds is about 15° , but this gradually flattens and the beds are nearly horizontal about three-fourths of a mile to the southwest. At its southeast extremity, in sec. 15, this fault becomes very irregular, being lost in an area of much broken and disturbed rocks in secs. 13, 14, 23, and 24.

Near the west line of T. 23 N., R. 14 E., there is a well-developed fault that has a slightly curving trend but extends in a general northerly direction. In secs. 13 and 24 this fault appears along the west side of Missouri River, where the Colorado shale abuts against the Virgelle sandstone and the upper members of the Eagle formation. The tilted strata, in which some petroleum or gas may have accumulated, lie east of this fault line, occupying a considerable part of the alluvium-covered areas along Missouri River. To the south the fault is much concealed by glacial drift, but in the N. $\frac{1}{2}$ sec. 36 it is again well exposed, trending in a northeasterly direction across the valley of Flat Creek. The tilted strata here also lie on the east side of the fault, the Colorado shale and Eagle sandstone being carried against the Eagle sandstone and Claggett shale on the west side. The dips are between 15° and 20° in the steeper beds, but they flatten to approximately horizontal a mile or so east of the fault line.

TILTED ROCKS OF LOWER PART OF JUDITH RIVER.

In the north half of T. 22 N., R. 16 E., there is an extensive fault cutting across the township with a trend about N. 65° W. Southwest of this fault there is a tilted block which is the largest of those in the region along the Missouri River described in this report. The tilted beds are best exposed along Judith River in secs. 10, 11,

14, and 15. At this locality the Colorado shale is the lowest formation exposed and is succeeded to the southwest by the Eagle and Claggett formations, and part of the Judith River, in normal succession. The tilted beds extend southwestward from the fault line for a distance of about 2 miles. In the S. $\frac{1}{2}$ sec. 15 they are cut by a small fault trending in a northeasterly direction, which probably meets the main fault near the west line of sec. 12. Along Missouri River near the north line of secs. 5 and 6, the main fault crosses Missouri River, bringing up the Colorado shale and the overlying formations. At this locality the area of tilted strata extends to the southwest about $1\frac{1}{2}$ miles from the fault line.

From sec. 6, T. 21 N., R. 16 E., a fault whose trace makes a slightly curved line extends eastward for a distance of over 12 miles into the townships adjoining on the east. On the north side of the fault there are tilted beds dipping about 8° N. The best exposures of these tilted rocks are along Judith River in the S. $\frac{1}{2}$ sec. 2, T. 21 N., R. 16 E. Here the upper part of the Colorado shale, overlain by the Eagle sandstone and the Claggett formation, are brought against shale in the lower part of the Colorado. In T. 21 N., R. 17 E., this fault extends in a slightly curved line southeastward through secs. 7, 8, and 16. In the N. $\frac{1}{2}$ sec. 22 it is broken by several cross faults, but its extension continues eastward, makes a sharp curve toward the south, and extends northeastward about 1 mile into T. 21 N., R. 18 E., nearly to the northeast corner of sec. 19. The beds on the north side of this fault dip northward at an average rate of about 7° .

TILTED ROCKS ON DOG CREEK.

At the mouth of Dog Creek, about 2 miles east of Judith post office, there is a thrust fault extending in a northerly direction, which crosses Dog Creek in the NE. $\frac{1}{4}$ sec. 6, T. 22 N., R. 17 E. West of this fault, which extends to and probably crosses Missouri River, there is an area of about 2 square miles of tilted beds which dip to the west. In this area the Colorado shale, overlain by the full thickness of the Eagle and a part of the Claggett shale, is carried upward against the lower part of the Claggett formation. The dips near the fault plane vary between 6° and 12° . About half a mile west of the fault they become steeper, averaging between 20° and 30° , and still farther west the beds flatten and approach a horizontal attitude within 1 mile of the trace of the fault.

In the north half of T. 21 N., R. 18 E., is a fault that extends across the township with a trend about N. 60° W. and brings a considerable block of tilted rocks, in which the Claggett shale is the lowest formation exposed, against nearly horizontal Judith River beds. This fault crosses very near the northeast corner of sec. 6 and extends about 4 miles northwestward from this point, into T. 22 N.,

R. 17 E. On the southeast it holds this trend to and beyond Dog Creek, in sec. 10, and is well exposed in the badlands along the creek. The tilted strata lie southwest of this fault and have an average dip of about 15° . Nearly horizontal beds are present within about $1\frac{1}{2}$ miles southwest of the fault line.

A fault that is probably a continuation of the fault last described extends due east from a point near the northwest corner of sec. 18, T. 21 N., R. 19 E., for a distance of nearly 4 miles. On the south side of this fault there is a considerable area of tilted and slightly folded strata, in which the upper half of the Judith River is the lowest formation exposed and is overlain normally by the Bearpaw shale to the south. These tilted beds are carried upward against nearly horizontal Bearpaw shale on the north side of the fault. A well-defined anticline in the tilted area on the south side of the fault was noted in secs. 17 and 18. Its axis passes through the center of sec. 18, with a trend about N. 75° E., and extends into the N. $\frac{1}{2}$ sec. 17, where the trend changes to nearly east. On the north limb of the anticline the rocks dip between 7° and 35° , and the steeper dips occur close to the fault line. On the south limb the dips vary between 6° and 12° . East of this fold, in an area of tilted strata lying south of the fault, the ground is much broken by short faults trending nearly at right angles to the principal break. The strata in this area are irregularly folded or bent but generally lie at low angles, the dips rarely exceeding 10° . In the S. $\frac{1}{2}$ sec. 17 there is a minor fault which can be traced for about a mile in a direction nearly due east and which offsets the coal zone in the upper part of the Judith River formation.

In the northeastern part of T. 21 N., R. 19 E., there are two faults lying nearly at right angles to each other, both of which have brought up the Judith River beds in an area in which the Bearpaw shale is the predominating formation. The longer of these faults crosses secs. 1, 2, and 12 in a direction about N. 60° W. On its northeast side the Judith River beds, overlain by the Bearpaw shale in normal succession, are tilted at angles varying between 40° and 50° within a quarter of a mile of the fault, but farther northeast the dip of the beds is less, and within 1 mile of the trace of the fault they are nearly horizontal. Southwest of the fault the Bearpaw shale, lying practically horizontal, occupies a considerable area. The other fault in the northeastern part of the township crosses sec. 13 in a direction about N. 50° E. and joins the fault just described in the SW. $\frac{1}{4}$ sec. 7, T. 21 N., R. 20 E. On the southeast side of this fault there is an area of titled upper Judith River and lower Bearpaw beds, which dip at angles ranging from 20° adjacent to the fault to 10° within 2,000 feet. This fault crosses Cutbank Creek about 1,500 feet north of the center of sec. 13 and is there well exposed, but to the

southeast it can not be traced more than a few hundred yards and probably dies out before reaching the west line of sec. 13. In the SE. $\frac{1}{4}$ sec. 13 the strata in the tilted block are folded into a shallow syncline, the south limb of which is near the south line of the section. The axis of this syncline trends northeast, nearly parallel to the fault.

AREA OF COLORADO SHALE EXTENDING FROM A POINT NEAR GREAT FALLS TO THE SWEETGRASS HILLS.

GENERAL FEATURES.

The results of six deep borings (see locations on the map, Pl. IV) are available for the area extending across the outcrop of the Colorado shale from Great Falls to the Sweetgrass Hills. None of these borings were successful, although five report showings of gas or oil, or both. These wells, located regardless of the structure, seem to show that a fair percentage of success can not be obtained by random drilling in the large area occupied by the Sweetgrass arch. Two of the wells are near the center of the arch, and seem to prove that this broad uplift as a whole has not caused the accumulation of oil or gas along its crest. However, if local folds are present within the broader uplift, they may have served as reservoirs for oil or gas.

The Bow Island gas field,¹ 60 miles north of the Canadian boundary, is near the northwestward extension of the Sweetgrass arch, its exact position probably being a little to the east of the crest of the arch. The details of the structure in the vicinity of the Bow Island field have never been published, but it is not improbable that the field is located on a local fold within the arch. The first well in this field was drilled about 1908. By 1914 sixteen wells had been completed, spaced about 1 mile apart over an area of about 15 square miles. The total production from these wells in 1914 was 75,000,000 cubic feet a day, and the gas was distributed from a 16-inch pipe line for 160 miles, supplying Lethbridge, Calgary, and intermediate towns.

DRILLING NEAR THE SWEETGRASS HILLS.

Several wells have been drilled within the last few years in the vicinity of the West Butte of the Sweetgrass Hills. These wells are about 3 miles northeast of the oil seep in the Colorado shale, described on page —. They were put down in a flat plain, much covered by glacial drift, and are not known to have been located with reference to local structure of any description. The general dip in the vicinity, as shown by a few scattered outcrops of the Virgelle sandstone, is northward at a low angle. The deepest of these wells was

¹ Clapp, F. G., and others, op. cit., pp. 276-277.

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drilled to a depth of 2,870 feet, nearly to the base of the Kootenai, and obtained small flows of gas at two horizons. According to W. A. English, of the United States Geological Survey, the seep on West Butte probably comes from the 50-foot member of the sandstone that is reported to contain water, whose base in this well is at a depth of 1,640 feet. A log of the well, furnished by E. C. Galbraith, of the General Land Office, is as follows:

Log of well in sec. 4, T. 37 N., R. 2 E., a few yards south of the international boundary.

[Elevation, 3,875 feet (barometric).]

Probable formation.	Driller's description of the rock.	Contents.	Thick- ness.	Depth.
			<i>Feet.</i>	<i>Feet.</i>
Glacial drift.	Glacial drift.....		65	65
Virgelle sandstone.	Light-colored sandstone.....		245	310
Colorado shale.	Black and dark-colored shale.....	Water.....	970	1,280
	Dark-colored shales.....		310	1,590
	Gray sandstones.....	Water.....	50	1,640
	Black sandy shale.....		20	1,665
	Gray sandstone.....	Gas.....	40	1,735
	Dark sandy shale.....		25	1,760
	Black sandy shale.....		45	1,805
	Gray sand.....	Salt water.....	5	1,810
	Black sandy shale.....		10	1,820
	Conglomerate.....		20	1,840
	Gray sandstone.....		40	1,880
	Black shales.....		180	2,060
Kootenai formation.	Bluish shales.....		70	2,130
	Red shale.....		68	2,198
	Gray shale.....		132	2,330
	Black shale.....		20	2,350
	Brown shale.....		150	2,500
	Sandstone strata.....	Gas and wa- ter.	170	2,670

A second hole was put down about a quarter of a mile southeast of the well just described and passed through the same strata. According to C. H. Jennings, who superintended the drilling of this well, shows of oil were encountered at about 960 and 1,660 feet, and small flows of gas at 1,300, 1,535, and 1,810 feet.

DRILLING NEAR KEVIN, TOOLE COUNTY.

A boring in search of oil was made about 8 miles southwest of Kevin, Toole County, on the James Miller ranch. It went to a depth of 1,755 feet, passing through part of the Colorado shale and all of the Kootenai formation, and probably entering the Jurassic. This well is in the midst of a large area of horizontal rocks, as shown by exposures in the vicinity and also by the lay of the Virgelle sandstone in the prominent escarpment to the west and north. This well was therefore drilled in an unfavorable structure position. Small

flows of gas, however, were encountered at three horizons. The log of the well, furnished by H. C. Price, of Great Falls, Mont., is as follows:

Log of well at the James Miller ranch, in the NW. $\frac{1}{4}$ sec. 25, T. 34 N., R. 4 W.

[Elevation, 3,260 feet.]

Probable formation.	Driller's description of the rock.	Contents.	Thick- ness.	Depth.
			Feet.	Feet.
Glacial drift.	Loam and gravel.....		40	40
Colorado shale.	Black shale.....		120	160
	Lime shell.....		2	162
	Black shale.....		153	315
	Sand.....	Gas and water.	5	320
	Gray-black shale.....		100	420
	Sand.....	Gas.....	10	430
	Sandy shale.....		30	460
	Hard dark shale.....		10	470
	Black shale.....		180	650
	Gray sandy shale.....		70	720
	Black sand.....		10	730
	Sandy shale.....		40	770
	Light shale.....		80	850
	Sandy shale.....		100	950
	Black shale.....		90	1,045
	Gray sand.....		20	1,065
	Sand.....	Gas, best flow.	5	1,070
	Black shale.....		30	1,100
Kootenai formation.	Light shale.....		15	1,115
	Red rock.....		35	1,150
	Light shale.....		45	1,195
	Hard shell.....		5	1,200
	Hard sand.....		25	1,225
	Shell.....		5	1,230
	Sand.....		70	1,300
	Light shale.....		60	1,360
	Sand.....		30	1,390
	Hard shell.....		10	1,400
	Light shale.....		60	1,460
	Hard sand.....		40	1,500
	Hard shell.....		10	1,510
	Hard sand.....		40	1,550
	Yellow shale.....		50	1,600
	Gritty sand.....		50	1,650
	Hard shell.....		5	1,655
	Black shale.....		20	1,675
	Hard shell.....		5	1,680
Jurassic.	Lime rock.....		50	1,730
	Black shale.....		25	1,755

DEEP BORINGS IN CHOUTEAU COUNTY.

About 10 miles southeast of Collins a prospect hole for oil and gas, known as the Banatyne well, was driven to a depth of 1,500 feet and obtained a small flow of gas at one horizon. The log for 1,240 feet of this bore, passing through the Colorado shale and into the Kootenai formation, is given below. This well is near the crest of the Sweetgrass arch, if that structure extends this far south of Teton River. Nothing is known of the local structure, and it is probable that the rocks are much concealed by glacial drift.

Log of Banatyne well, 10 miles southeast of Collins.

Probable formation.	Driller's description of the rock.	Contents.	Thick- ness.	Depth.
			<i>Feet.</i>	<i>Feet.</i>
Glacial drift.	Yellow clay		74	74
Colorado shale.	Shale		206	280
	Sand	Salt water and gas.	5	285
	Sandy shale		73	358
	Black sand		7	365
	Shale		135	500
	Sand		9	509
	Sand and gritty shale	Salt water	96	605
	Soft white conglomerate		175	780
	Hard conglomerate		90	870
	Fine blue sand		10	880
	Hard blue shale		20	900
	Hard shale in thin layers		50	950
	Dark-blue shale		25	975
	Black shale		65	1,040
	Hard bluish sandstone		90	1,130
	Black shale		30	1,160
Kootenai formation.	Red limestone		40	1,200
	Red sandstone		40	1,240

Small flows of gas are also reported from two deep wells in the northeastern part of Chouteau County. One of these, 15 miles northwest of Fort Benton, obtained gas in the Colorado shale at a depth of 300 feet. The other gas well is 10 miles north of Virgelle and was drilled to a depth of 800 feet. Details of the structure in the vicinity of these borings are not known.



DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 641—D

STRUCTURE OF THE
VICKSBURG-JACKSON AREA, MISSISSIPPI

WITH SPECIAL REFERENCE TO OIL AND GAS

BY

OLIVER B. HOPKINS

Contributions to economic geology, 1916, Part II

(Pages 93-120)

Published July 18, 1916



WASHINGTON

GOVERNMENT PRINTING OFFICE

1916

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ILLUSTRATION

PLATE VIII. Map of Vicksburg-Jackson area, Mississippi..... In pocket.

STRUCTURE OF THE VICKSBURG-JACKSON AREA, MISSISSIPPI, WITH SPECIAL REFERENCE TO OIL AND GAS.

By OLIVER B. HOPKINS.

INTRODUCTION.

Many facts have combined to lead the people of Mississippi to believe that oil and gas may be found in that State, among them the extensive development of the oil and gas fields in Louisiana; the situation of the State between the Appalachian fields and those of the coastal region; the supposed indications, such as gas seeps and iridescent films resembling oil found on stagnant pools of water; and finally the results of the work of so-called "oil experts," who have located "streams" of oil crossing the State. Though the United States Geological Survey does not consider these reasons conclusive, others of a general geologic nature are considered worthy of investigation and of sufficient significance to justify the hope that the oil and gas pools of the Coastal Plain may not be confined to Louisiana and Texas but may extend eastward into Mississippi. The presence in that State of beds which are of the same geologic age as those that bear oil in Louisiana, which are similar in composition to those beds, and which were deposited under similar conditions, and the possibility of finding rock folds here like those of that region, are considered significant.

It has been shown that the inclination or dip of the beds of rock, commonly called geologic structure, is the most potent factor in influencing the accumulation of oil in commercial pools. Consequently the study of the attitude of the rocks of the region and the location of rock folds, particularly arches (anticlines) and domes in the beds, leads to the location of areas in which oil and gas are most likely to be present. Such a study is of value to the oil prospector in that it makes possible the separation of favorable from unfavorable areas, and increases his chance of success. It should be understood, however, that any drilling outside of proved territory is in the "wildcat" class, even though the wells are drilled on anticlines, for other conditions, which can not be detected at the surface, may prevent the accumulation of oil and gas.

The object of this report is to show which of the areas in west-central Mississippi that were examined by the Survey are considered favorable and which unfavorable for the accumulation of oil, to discourage drilling in the unfavorable localities and thus to aid those interested in making conclusive tests to determine the presence or absence of oil and gas in the region.

Examination of the geologic structure in this region shows that sands corresponding to or possibly identical with those of northwest Louisiana dip deeply beneath the younger formations which compose the surface rocks, and that the rock beds in this region are similar to those in northwest Louisiana. The most pronounced fold is found near Jackson, and this fold appears more promising for wildcat testing with the drill, because if oil or gas are present this structure is more favorable for their accumulation. Other folds, one near Vicksburg and another near Eldorado, also invite tests. It must not be forgotten, however, that the formations carrying the oil sands in the Caddo region are here much more deeply buried, and that the sands in this deeper part of the Mississippi embayment may contain water instead of oil and gas.

FIELD WORK.

The field work for that part of this report which deals with the area near Vicksburg was begun by G. C. Matson, E. H. Finch, and the author in March, 1915. In June the work was extended northward and eastward by the author from Vicksburg to Satartia and along Big Black River from Bovina to Bentonina, thus completing the work on the area covered by an advance notice given to the press September 1. In October and November, 1915, the author spent five weeks in extending the work eastward to include the region near Jackson.

The field work consisted largely of tracing out different beds of the Vicksburg limestone, which were used as keys to the structure, and determining the elevations of these beds at different places. Other beds, both above and below the Vicksburg limestone, were used locally to determine the dip and the general structure, although only those within the limestone formation itself could be traced accurately from place to place throughout the area. Because of the hardness of the middle limestone member of the Vicksburg, and consequently because of its better exposures, its top was used as the datum for the structure contours. The different parts of the Vicksburg have persistent features by which they can be clearly recognized, and, as the distance between them is known, the elevation of the top of the limestone may be estimated at places where it is not exposed. As the dip of the beds is slight, at few places greater than 60 feet to the mile, it was necessary to determine its elevation with considerable

accuracy. Elevations above sea level were accepted as determined by the United States Geological Survey in the Vicksburg, Jackson, Florence, and Raymond quadrangles; by the United States Coast and Geodetic Survey along the line of the Alabama & Vicksburg Railway from Brandon to Edwards; by the War Department along the east bluff of Yazoo River from Redwood to Satartia; and by the Agricultural Department along Big Black River from Bentonina south to Bovina. In the region east of the Big Black, the elevations of outcrops were determined almost exclusively from level lines run by plane table from the nearest bench mark. Some leveling was done in this way west of the river, but most of the work there was done with an aneroid barometer. This method is fairly reliable and was considered necessary, for the outcrops lay in deep, densely thicketed hollows along the bluffs of Big Black and Yazoo rivers, and it would have been impossible to complete the work within the time and money available if level lines had been run to them, and as the elevations were known at almost all points along the river valleys at the foot of the bluffs the elevations determined by the aneroid could be checked within a short time, before changes in atmospheric pressure could affect the results. Elevations in the area between Big Black and Yazoo rivers were not important, as few significant exposures were found there; some were determined, however, with an aneroid, which was carried between two bench marks and error eliminated by comparison with the barograph records of the United States Weather Bureau at Vicksburg.

ACKNOWLEDGMENTS.

The author is indebted to Mr. G. C. Matson for part of the field work and to a greater extent for his criticism and supervision. Mr. Matson traversed a large part of the area west of Big Black River and verified the results which the author had worked out in detail.

To Mr. E. H. Finch the author is indebted for a number of logs of wells at and near Vicksburg, some of which he obtained personally and others through correspondence.

To Mr. C. W. Cooke the writer is indebted for the identification of a number of collections of Eocene fossils taken from deep wells. The data thus obtained were used in estimating the thickness of the Jackson formation and the Claiborne group in this area.

The author has used freely the reports that deal with the region, especially those by Hilgard¹ and Crider.² From these reports, particularly from Hilgard's, a list of a number of obscure outcrops was obtained.

¹ Hilgard, E. W., Report on the geology and agriculture of Mississippi, 1860.

² Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, 1906.

LOCATION OF THE AREA.

The area discussed in this report covers about 30 townships, or 1,080 square miles, and includes the greater part of Warren and Hinds counties, the southern parts of Yazoo and Madison counties, and the western part of Rankin County, in west-central Mississippi. It is roughly rectangular, 40 miles long and 25 miles wide, and extends from Vicksburg eastward a short distance beyond Jackson. Vicksburg lies in its southwestern corner and Jackson occupies an east-central position within it. It is bounded on the west by Yazoo and Mississippi rivers, and is traversed roughly from north to south by Big Black and Pearl rivers in its western and eastern parts, respectively. (See Pl. VIII, in pocket.) The Alabama & Vicksburg Railway crosses the area from east to west in its south-central part; the Yazoo & Mississippi Valley Railroad runs north and south through Vicksburg in its western part; and the Illinois Central and the Gulf & Ship Island railroads cross its eastern end through Jackson.

TOPOGRAPHY.

The topography of the Vicksburg-Jackson area is no more diversified than that of other areas in the Coastal Plain where the maximum relief does not exceed 300 feet, the maximum elevation above sea level is not greater than 500 feet, and where there are only slight differences in the hardness of the rocks. The main features are the broad, flat valleys that cross the region in general from north to south and the interstream areas, which in the western part of the area are much dissected and have angular topographic features and in the eastern part are flat or rolling plains.

The elevation of the broad river bottoms increases from west to east; that of Yazoo River is about 100 to 110 feet, of the Big Black 130 to 150 feet, and of the Pearl 260 to 280 feet. The hills between the Yazoo and the Big Black rise abruptly from the river bottoms to elevations of 250 to 350 feet above sea level. This area is deeply dissected by small streams that have carved into it an intricate system of deep hollows and steep ridges, which are characteristic of the loess that covers it and hides the underlying rocks.

East of the Big Black the loess becomes thinner and disappears and the rough country gives place to the broad, flat or rolling "prairie" lands of the Jackson clay. These rolling lands, which have a general elevation of 350 feet, prevail in much of this area but give way along the line between Hinds and Madison counties to the rough hilly country which forms the divide between Pearl and Big Black rivers. The hills that form this divide have a maximum elevation of about 475 feet and are outliers of high terrace deposits, of sands of the upper part of the Jackson formation, and in a few places, of Vicksburg limestone.

GEOLOGY.

STRATIGRAPHY.

FORMATIONS PRESENT.

All the rocks of the Vicksburg-Jackson region are sedimentary in origin and relatively young, the exposed rocks ranging in age from Claiborne (Eocene) to Recent, as shown in the upper part of the following table. The formations below the Claiborne will be reached in deep drillings.

Section of formations in Vicksburg-Jackson area.

System.	Series.	Group or formation.	Thickness.	Character.
Quaternary.	Recent.	Alluvium.	<i>Feet.</i>	Sand, clay, and silt along present streams.
	Pleistocene.	Loess and yellow loam.	0-100	Clay, fine gray to buff, calcareous, and yellow to brown loam.
		Alluvial terrace deposits.	0-50	Sand, gravel, and clay.
Tertiary.	Pliocene.	Sand and gravel.	0-50	Terrace sand and gravel.
	Oligocene.	Catahoula sandstone.	0-75	Unconsolidated sands, sandstones, gray siliceous clay, and some lignitic material.
		Vicksburg limestone.	80-130	Marl and clay above, containing marine shells; limestone and impure limestone and marl below.
	Eocene.	Jackson formation.	250-500 (?)	Sand above, cross-bedded, green to yellow nonfossiliferous; gray clay weathering black below and sand beds at base. Both clay and sand beds contain marine shells.
		Claiborne group.	500-1,000	Marls, sands, lignitic clays, and lignite above; quartzite, clay stone, and marl below.
		Wilcox group.	850-1,500 (?)	Lignitic clays and sands, with sand predominating in middle part.
Cretaceous.	Upper.	Midway group.	100-300	Clay, dark gray to black, and micaceous sandstone, with hard limestone and sandy marl below.
		Ripley formation.	50-300	Sands, clays, marls, and impure limestones of marine origin.
		Selma chalk.	600-1,000	Chalky limestone with argillaceous and sandy beds.
		Eutaw formation.	300-400	Sands, massive and cross-bedded.
		Tuscaloosa formation.	100-300	Irregularly bedded sands, clays, and gravels, containing clay and lignitic layers at top.

Of these formations the loess and the Jackson underlie by far the greater part of the area, and the Vicksburg and Catahoula formations and terraces sand and gravel smaller areas. The Claiborne occurs in a very small area near Jackson. The lower formations, with the possible exception of the Wilcox, have not been penetrated, so far as known, in this area.

CLAIBORNE GROUP.

The only beds of Claiborne age in this area are exposed near the northeastern part of Jackson in the bottoms of some small branches. Good exposures are found along Moodys Branch, in the S. $\frac{1}{4}$ sec. 35, T. 6 N., R. 1 E., and along another small branch a mile farther northeast in the SW. $\frac{1}{4}$ sec. 25 of the same township. These exposures consist of green micaceous sand and clay containing streaks and scattered particles of comminuted vegetable matter. Hilgard¹ says that "at the penitentiary well, after passing through 32 feet of surface material and fossiliferous strata of the Jackson age, lignitic clay was penetrated for 418 feet, after which a bed of shells 20 feet thick, extremely rich in greensand, was passed through into water-bearing sand." T. W. Vaughan² considers that the lignitic sand and clay intervening between the marine fossiliferous Jackson and the marine Claiborne occupy precisely the stratigraphic position of the Cockfield formation of Louisiana and applies that name to them here.

JACKSON FORMATION.

The weathered outcrops of the Jackson formation cover probably half the eastern part of the area and form the dark-colored sticky soil which characterizes so much of it. Its type locality is in and near the city of Jackson where, for such a soft, easily eroded material, it is well exposed. On lithologic grounds Lowe³ has divided the formation into three members, called by him Moodys Branch marl, Yazoo clay, and Madison sand, which are clearly recognized, although it is questionable whether the "Madison sand" properly belongs to the Jackson or to the overlying Vicksburg.

The lower division, the Moodys Branch marl of Lowe, is so called from its exposure in a branch so named in the eastern edge of Jackson. Here it is composed of a dark-green to yellow glauconitic

¹ Hilgard, E. W., Report on the geology and agriculture of Mississippi, p. 123, 1860.

² Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, p. 738, 1912.

³ Lowe, E. N., Mississippi, its geology, geography, soils, and mineral resources: Mississippi Geol. Survey Bull. 12, p. 81, 1915.

sandy marl, containing an abundant marine fauna, and has a thickness of 25 feet, according to Lowe.¹

The marl of Moodys Branch grades upward into the typical gray to yellow calcareous plastic clay, which is in places a clay marl, and has a total exposed thickness of about 80 feet at Jackson. This lithologic division of the Jackson outcrops in numerous small exposures along roadsides and streams over a wide area, and in the bluff at Yazoo City there is 120 feet of bluish-green fossiliferous marly clay containing gypsum in the upper part. Similar material, containing beds of fine-grained micaceous clay marl, outcrops at intervals for a distance of 15 miles south of Yazoo City, and 75 feet of similar material occurs in a hill 1 mile southeast of Satartia. This wide belt of outcrop suggests a considerable thickness if the dip is uniform; but as the beds do not dip uniformly here, no reliable estimate can be made. Some records of wells in the southwestern part of the area indicate a thickness of 350 to 500 feet for this division. (See well log, p. 120.)

These beds of clay have a marked tendency to slump or creep, as is well shown in the bluffs at Yazoo City and in any railroad cuts which expose this material, as those just south of Cynthia. When fresh these clays and clay marls are bright green to bluish green, massively bedded and jointed, as shown in a deep hollow half a mile northeast of Mechanicsburg. In weathering they form a lumpy or hackly clay of yellowish to brownish-yellow color and finally make a dark, sticky soil, which covers large areas in Hinds and Madison counties.

These clays grade imperceptibly upward into the "Madison sand," which is nonfossiliferous. The gradation of these sands into the marine Jackson below and Vicksburg above and the absence of fossils make it difficult to determine to which formation these non-marine beds belong. From the lithology and from a consideration of this small area only a line of separation could be drawn best at the small lignitic bed below the base of the fossiliferous Vicksburg. In the absence of definite information regarding the age of these sand beds, the usage in previous reports will be followed in considering them Jackson, although the evidence presented under the heading "Vicksburg limestone" (see p. 103) seems to indicate that the upper part, at least, is Vicksburg in age.

¹ Op. cit., p. 81.

The following sections show the general nature of the beds between the marine Jackson and Vicksburg formations:

Partial sections of Jackson and Vicksburg formations.

Forest Hill School, $5\frac{1}{2}$ miles southwest of Jackson.

	Ft.	in.
Limestone, pure, white, partly weathered.....	3	0
Limestone or marl, soft, sandy, containing hard nodules and marine shells.....	3	0
Clay, gray, sandy, nonfossiliferous, containing lime nodules now altered to chalk.....	4	0
Sand, pure quartz.....	3	0
White chalk layer.....		1
Sand and clay, gray, laminated.....	4	0
Streak of earthy lignite.....		2
Clay, drab, sandy.....		6
Sand, medium to fine grained, containing thin ferruginous and clayey layers.....	6	6
Sand and clay, laminated, cross-bedded.....	2	0
Sand, hard, cross-bedded, containing some thin clay laminae above and numerous thin platy layers of ferruginous sandstone throughout.....	12	6
Same as preceding bed; sand green when fresh and yellow when weathered, thick bedded below and thinner above...	25	6
Clay, drab, sandy, grading downward into typical Jackson clay with plastic gray calcareous clay of Jackson forma- tion below.....	10	0
	125	5

Rocky Hill Church, 10 miles north of Jackson.

Limestone, in hard and soft layers.....	25	0
Sand, massive, yellow.....	4	0
Clay, brown, carbonaceous, gypsiferous.....	1	0
Sand, micaceous, and numerous thin clay layers.....	12	9
Sand and small amount of clay.....	4	0
Sand, micaceous, and numerous thin clay layers.....	7	4
Sand alternating with thin clay beds.....	19	6
Sand, hard, yellow, and little clay.....	8	3
Sand, argillaceous, becoming dominantly clayey below.....	16	1
Clay, slightly sandy above, grading to plastic gray clay of Jackson type below.....	27	6
	125	5

These sand beds are well exposed in fresh condition at two localities, one in the northwestern part of the area and the other in the southeastern, and they have been found to be closely similar. In the southern part of sec. 15, T. 4 N., R. 1 E., $3\frac{1}{2}$ miles south of Plain, there is exposed below a 6-inch bed of hard lignite, which occurs near the base of the fossiliferous Vicksburg, 30 feet of thinly laminated, micaceous, highly cross-bedded, nonfossiliferous sand, which is green when fresh and weathers to a rusty yellow color; it is car-

bonaceous above but is less so below and is underlain by a bed of stiff gray clay in the creek bottom. In a deep ravine near S. T. Dilley's house, 1 mile north of Phoenix, there is exposed 30 to 40 feet of bluish-green micaceous sand, thin carbonaceous streaks, grayish-green clay, and laminated sands and clays containing much comminuted vegetable matter. This section differs from the one south of Plain in the presence of more vegetable matter and clay. Here silicified wood is very abundant, and numerous trunks and fragments of trees may be seen in place. At the outcrop of these beds along Pearl River silicified logs are abundant in the river bed. The thickness of this sand member differs from 60 to 80 feet in this area.

VICKSBURG LIMESTONE.

The type locality of the Vicksburg limestone is in the bluffs near the city of Vicksburg, where almost its entire thickness is exposed. It is composed largely of limestone and marl, which represent the latest marine deposits in the area. From the area south of Vicksburg outcrops of this formation are found at intervals for a distance of 30 miles in a north-northeasterly direction along the east bluff of Yazoo River almost to Satartia; here the outcrop changes its course and crosses the State into Alabama in a fairly uniform southeasterly direction, with the exception of a U-shaped bend to the south around Jackson. The formation is thin and consequently its outcrop is narrow, but owing to the presence of relatively hard limestone beds near its middle part it outcrops at numerous places and can be readily traced across the area, except where it is covered with loess.

The following section shows the relationship of the Vicksburg to the Jackson below and the Catahoula above:

Composite section of Vicksburg limestone and parts of adjacent formations as shown near Vicksburg and along bluffs of Yazoo River.

Catahoula sandstone:

Exposed near pesthouse, Vicksburg:	Feet.
22. Sandstone, medium grained, white, differing in induration from soft to quartzitic, interbedded with gray siliceous clays.....	20
21. Clay, gray, and soft sandstone layers; clay is deep blue when fresh and weathers through greenish to gray, in part plastic and in part highly siliceous.....	35

Vicksburg limestone:

Exposed in bluff at Waltersville near Vicksburg:	
20. Sandy clay, chocolate-colored, fine grained, carbonaceous, nonfossiliferous.....	20
19. Sand, fine grained, laminated, nonfossiliferous....	6
18. Marl, glauconitic, and soft marly limestone with some sandy, argillaceous layers; contains marine shells	35

Vicksburg limestone—Continued.

Exposed at Haynes Bluff:		Feet.
17. Limestone, hard, brown, ferruginous.....		5
16. Limestone, hard and soft layers interbedded.....		17
15. Limestone, soft, marly, blue when fresh and gray to yellow when weathered.....		4
14. Limestone, hard, containing few fossils.....		3
13. Limestone and marly limestone, marine shells abundant; where exposed in bed of streams causes small falls.....		17
12. Clay, dark grayish green; contains marine shells..		1½
11. Shell marl, carbonaceous, arenaceous.....		3
10. Shell marl, sandy; at top of lower falls very fos- silliferous.....		3
Exposed near southern edge of E. A. Archer's property near Eldorado:		
9. Clay, carbonaceous, nonfossiliferous.....		10
8. Sand, green, calcareous; contains marine shells...		4
7. Concretionary limestone layer with shells abun- dant.....		1
6. Sand.....		2
5. Shell rock, coquina.....		1
Jackson formation:		
Exposed near southern edge of E. A. Archer's property near Eldorado:		
4. Shale, brown, carbonaceous, with thin sandy layers.....		11
3. Sand, medium grained, orange to yellow.....		12
2. Sandstone, ferruginous.....		2
1. Shale, green, sandy, and sand interlaminated.....		5
		217½

The conditions at the close of the marine Vicksburg were very much the same as at the beginning, as the carbonaceous beds both above and below indicate. The small streaks of lignite at the base of the marine Vicksburg show that swamps existed immediately preceding the transgression of the sea, which caused the deposition of the limestone above. Although this change in many places is abrupt, there seems to have been continuous deposition or at least no interval of erosion from Jackson into Vicksburg time, and while shallow-water and non-marine deposits were forming here, farther east in Alabama marine conditions continued without a break.¹

At the close of the Vicksburg the conditions were similar to those at the beginning. The withdrawal of the sea led to the formation of carbonaceous clays and sands, which gradually gave place to the siliceous clays and sandstones that compose the Catahoula formation. Thus deposition is believed to have been continuous from the Vicksburg into the Catahoula.

¹ Smith, E. A. The underground water resources of Alabama, p. 19, Alabama Geol. Survey, 1907.

The Vicksburg may be conveniently divided into four parts. Its basal beds consist of dark-colored, in places highly carbonaceous, fossiliferous sand and clay, which grade upward into sandy marl and are separated from the nonfossiliferous sands below by a thin but fairly uniform bed of carbonaceous clay or lignite. These beds are 20 to 25 feet thick in the bluffs along Yazoo River and thin out to the east, so that in the vicinity of Jackson the limestones above rest directly on unfossiliferous sands and clays below. (See sections at Forest Hill and at Rocky Hill, p. 100.) This apparent thinning is doubtless due to the fact that these beds become more sandy and unfossiliferous to the east and thus appear to represent the top part of the sands below. In other words, part at least of the sand beds in the sections near Jackson are of Vicksburg age and were laid down contemporaneously with the lower fossiliferous beds along Yazoo River.

Above the fossiliferous sand, clay, and marls there are limestones, impure limestones, and marls interbedded in layers from 1 to 3 feet thick, forming numerous small bluffs. The harder beds of limestone are semicrystalline; the marly beds are soft when first exposed but harden on drying. Both the limestone and the marl are more or less glauconitic and are bluish gray when fresh, but weather to gray or yellow. These beds are the most easily and definitely recognized of the entire section in the region and have been used as the basis for structure contours. The thickness of this limestone unit decreases from 35 or 45 feet in the western part of the area to about 30 feet in the eastern part near Brandon and along Pearl River below Jackson.

This limestone unit is overlain by dark-gray micaceous sandy marl, shell marl, and some chalky limestone layers. It is less calcareous above and more argillaceous and in places carbonaceous. The thickness of this calcareous fossiliferous unit is 30 to 35 feet along the Yazoo bluffs and decreases to about 15 feet in the vicinity of Jackson. This marl is bluish or greenish when fresh and is usually somewhat glauconitic. Owing to its softness it weathers readily and is well exposed in few places.

In the western part of the area the marl is overlain by 5 to 10 feet of fine gray argillaceous sand, which is nonfossiliferous and which is succeeded by 20 to 25 feet of chocolate-colored fine-grained sandy clay, which grades upward into the gray siliceous clays of the Catahoula formation. To the east this unit thins so that on Big Black River near Edwards it is not over 18 feet thick. Beyond Pearl River, on the Gulf & Ship Island Railroad (see section, p. 104), the fossiliferous marls are immediately overlain by the gray, siliceous clays, characteristic of the Catahoula formation. Along the river south of Byram, however, the section is in every way similar to that farther west. (See section, p. 104.)

This upper nonfossiliferous unit is tentatively considered part of the Vicksburg because the fossiliferous beds at the top of that formation grade into this material and are interbedded with it. The dividing line is placed at the top of these beds, where they are in contact with typical Catahoula clay, although there are similar beds of carbonaceous clays and sands within that formation.

The thickness of the Vicksburg limestone decreases from 120 or 130 feet in the western part of the area to 80 or 100 feet in the east-ern, due largely to the thinning of the lowest division.

The character of the individual beds of the upper division of the Vicksburg formation is shown in the following sections:

Partial section of Vicksburg limestone along south side of Wanaley Bend on Pearl River in west-central part of sec. 36, T. 4 N., R. 1 W.

Clay, carbonaceous, nonfossiliferous, in part massively bedded.	Ft. in.
Marl, green, glauconitic; contains marine shells	5 6
Limestone, hard, nodular, irregular layers	6
Marl, green, glauconitic, weathering gray to yellow	3 0
Limestone, hard ledge	9
Limestone, soft, or marl	1 1
Limestone, hard ledge	1 6
Marl, green, glauconitic	6 0
Limestone, hard ledge	1 6
Limestone, soft, chalky	3 0
Clay, light colored	6
Marly limestone, light bluish green; marine shells abundant	3 0
Marl, clayey in lower part	2 6
Limestone, hard ledge	1 6
Limestone, soft, marly	1 0
Water level in Pearl River.	
	31 4

A more detailed section of the beds which compose the limestone unit of the Vicksburg formation is given below:

Section of Vicksburg limestone on Gulf & Ship Island Railroad, 1½ miles south-east of Plain, Miss.

	Ft. in.
Clay, gray, plastic, nonfossiliferous, weathering yellow	8 0
Clay, plastic, containing white chalky layers and concretions, light tan when fresh and dark brownish when weathered; marine shells abundant	5 6
Marl, light yellow, sandy; contains marine shells	4 6
Limestone, chalky, and marl, white to yellowish in color, containing abundant small white lime concretions	2 0
Shell bed, slightly indurated	4
Marl, ferruginous, sandy, containing hard limestone nodules and abundant fossils	1 0

	Ft.	in.
Shell bed, orbitoides, pectens, and the like-----		6
Marl, sandy; shells abundant, especially in lower part-----	1	6
Limestone, soft-----	2	3
Limestone, hard ledge, with irregular base-----	2	3
Limestone, medium soft-----	2	0
Limestone, soft, marly-----	1	0
Limestone, hard-----	1	6
Shell marl, soft-----	2	3
Limestone, hard-----	1	0
Limestone, soft, shelly-----	3	4
Limestone, hard ledge, light colored-----	2	9
Marl, soft, sandy; contains marine shells; concealed below--	1	6
	43	2

CATAHOULA SANDSTONE.

The nonmarine sandstones and clays of the Catahoula formation underlie the southern part of the area and cross it in a general southeasterly direction parallel to the outcrop of the Vicksburg limestone. The type locality of the Catahoula is not far south of Vicksburg, in Catahoula Parish, La., opposite the exposures at Grand Gulf, from which the formation was formerly named, and practically duplicates them. The lower 25 to 50 feet of the Catahoula consists largely of bluish and greenish siliceous clays, which weather gray and are interbedded with soft white sandstones and plastic clays. Higher the formation consists of clays like those below—sandstones, quartzites, carbonaceous clays, and thin beds of lignite.

These materials do not extend over large areas as continuous beds but occur as disconnected lenses. The sands range in induration from almost loose materials through sandstones to dense quartzites, their hardness depending on how firmly the sand grains are cemented. The cement consists of white, opaque silica, which stands in sharp contrast to the translucent quartz grains and is a characteristic feature of the formation. Much of the so-called clay is composed largely of finely divided silica.

Section of Catahoula sandstone along road one-half mile west of Byram.

	Feet.
Clays, dark, carbonaceous.	
Sandstone, bluish white, soft, and clay with some hard layers.	20
Clay, siliceous, and sand, partly concealed-----	20
Sandstone, hard, white-----	3
Sandstone, thin beds, separated by gray clay-----	2
Clay and sand, gray to yellow-----	10
	55

Another section of the Catahoula, which shows its range in lithology, is as follows:

Partial section of Catahoula sandstone, sec. 19, T. 5 N., R. 1 W., 11 miles west of Jackson.

Hilltop.	Ft.	in.
Sand, fine, gray, containing thin clay layers-----	5	0
Sandstone, hard, medium grained-----		8
Sand and clay, hard, yellowish gray-----	1	6
Sandstone, medium fine grained, micaceous, cemented with opaque silica-----	2	0
Clay, hard, carbonaceous, siliceous-----	1	0
Clay, hard, gray, siliceous-----	20	0
Lignite, impure-----		4
Sand, gray, argillaceous-----	1	2
Sandstone, hard, fine grained; containing gray siliceous clays at foot of hill-----	1	0
	32	8

Only the lower part of the formation is exposed in this area, and where it occurs the structure is generally low and not favorable to accumulation of oil and gas; therefore this formation is not likely to be penetrated by the drill in testing the area.

SAND AND GRAVEL.

After the deposition of the Catahoula sandstone there was a period during which no sediments were laid down in this region and those that had been formed were gently folded and extensively eroded. Upon this eroded surface gravel and sand were laid down when the land surface was relatively much lower than now. Small remnants of one of the high terraces capped by these materials are now found in the eastern part of this region at an elevation of almost 500 feet above sea level. As the country was gradually uplifted and eroded other terraces were formed at progressively lower levels, and the wearing away of the upper terraces yielded a large part of the material for the lower ones.

The scattered remnants of terrace gravel, together with the weathered outcrops of some of the older sandy formations, were formerly classed as "Orange sand" by Hilgard,¹ who considered this material to represent a mantle of surficial deposits spread over the older rocks. Later the formation was more restricted and renamed "Lafayette."² Still closer study has led to the separation of most of that part of Hilgard's formation and also of the "Lafayette"

¹ Hilgard, E. W., Report on the geology and agriculture of Mississippi, pp. 5-46, 1860.

² G. C. Matson has recently applied the name Citronelle formation to the upper terrace deposits of Pliocene age. (Matson, G. C., and Berry, E. W., The Pliocene Citronelle formation of the Gulf Coastal Plain and its flora: U. S. Geol. Survey Prof. Paper 98-L, 1916.)

which represented the oxidized outcrops of the older formations from the true terrace sands and gravels, which in many places they closely resemble. In this region the weathered outcrop of the sands between the marine Vicksburg and Jackson formation commonly resembles the sandy terrace deposits.

These terrace deposits, which are progressively younger from the highest to the lowest, are composed of orange or yellow, medium to coarse grained sand and gravel and irregular layers and pebbles of clay. The gravels average probably an inch in diameter, but some are as much as 3 inches or more. They consist largely of fairly angular chert pebbles and of less numerous well-rounded quartz pebbles. The chert pebbles contain many fossils which show clearly that they came from the area of Paleozoic rocks to the north or northeast. The deposits range in thickness in this area from a few inches to 50 feet or possibly more.

The gravel is most abundant on high hills, as the upper terrace deposits were less sandy and contained a greater amount of coarse-grained material than the lower ones. Gravel beds of considerable extent occur at many places along the bluffs of Yazoo River, near Champion Hill, a few miles northeast of Edwards, and north of O'Neal schoolhouse near Tinnin. At a number of places these gravel beds are worked for road metal. Large exposures of sandy terrace deposits are found along the road one-third mile south of McRaven, and one-half mile south of Taylorsville; orange-colored sand more than 50 feet in thickness is present.

LOESS AND YELLOW LOAM.

The loess is the most conspicuous formation in the western part of the Vicksburg-Jackson area and hides the older formations over a large part of it. Its western limit is the east bank of Mississippi and Yazoo rivers, where it has its maximum thickness of 50 to 100 feet. From this region it originally spread east, diminishing in thickness and covering both hills and valleys for a distance of 15 to 20 miles.

The loess is a gray or buff calcareous material composed largely of fine sand and containing lime nodules and snail shells; the yellow loam is less calcareous and in part coarser grained and does not contain fossils. The loam is more variable in composition than the loess and in places contains a large amount of medium-grained sand. It underlies the loess. The loess forms smooth, almost vertical exposures; the loam forms equally steep slopes but develops a buttressed or crenelated appearance and on further weathering shows a roughened, cracked surface which differs from that of the loess. The loess gradually disappears a few miles east of Big Black River; the

loam, however, is well developed where the loess disappears and extends, though diminishing in thickness, 5 to 10 miles farther east. The loess gives rise to a peculiar topography (see p. 96), which is characterized by steep slopes and irregular drainage. Old roadbeds are in places entrenched 40 to 50 feet in it where the roads descend from the hills to the valleys, and in rough country the roads are worn to an even grade by traffic and running water acting on the homogeneous material. The loess shows very faint lines of stratification, if any, and appears to consist of a uniform mass of fine dust-like material. In many railroad cuts it shows distinct lines parallel to the surface configuration, which appear to represent a feature of surface weathering.

The loess is believed to be a wind-blown deposit, which was brought up from extensive mud flats that bordered the Mississippi below its bluffs during the glacial and interglacial stages and spread over the bluffs to the east of the river.

STRUCTURE.

GENERAL FEATURES.

The general structure of the Gulf Coastal Plain is simple. A series of beds slopes gently southward and passes successively deeper and deeper beneath more recent deposits toward the coast. This general dip toward the coast is interrupted by local steepening or flattening and in a few places by a reversal in direction. These irregularities of dip, which are of greatest significance in the accumulation of oil and gas in valuable pools, are well illustrated in the Vicksburg-Jackson area.

The principal structural features of this area are the Jackson anticline, the Vicksburg monocline,¹ and the Eldorado monocline. There are other features which are small, irregular, and not well outlined. The two monoclinal folds are believed to be older than the Jackson anticline, which has interrupted their eastern extension. These structural features are post-Catahoula in age and probably in large measure earlier than the highest terrace deposits.

METHOD AND ACCURACY OF REPRESENTATION.

Structure may be thought of as the surface form of a single stratum of rock, including its upfolds, or anticlines, and its downfolds, or synclines. The shape and location of such folds are best represented on a map by contours, or lines connecting points of equal ele-

¹ The term monocline here signifies the downward bend and tilted portion of a series of approximately horizontal beds. A series of such monoclines produces step folds with structural terraces between them.

vation on the stratum taken for reference, which in the area here considered is the Vicksburg limestone. On the accompanying map the lines are drawn at intervals of 20 feet and are marked with the elevation above sea level of the top of the hard middle limestone member of the Vicksburg. It is evident that the lines of different elevation will be close together where the rocks dip steeply and far apart on gentle slopes, and the dip is from the contour with the higher number to the adjoining one with a lower. Thus contours represent both the direction and rate of dip.

The hard limestone near the middle of the Vicksburg formation (Nos. 17 to 13 in the section, p. 102) was chosen as the datum of reference, or key rock, because it contains the most clearly recognized and easily traced beds in the region. Elevations were taken on all the outcrops of this limestone in the area, and where the outcrops are numerous the structure is definitely determinable and is outlined with solid contour. Where so represented the contours are believed to be correct within 10 feet. Where exposures of the limestone are far apart, and where other less well-defined beds were used for reference and the interval to the limestone calculated, broken contours are used. Finally, where the data were still less reliable the broken contours are questioned. In general, it is believed that the unquestioned broken contours are correct within 20 feet. Although much of the structure is outlined by broken contours, there are enough solid ones to show that the structure is essentially as represented.

JACKSON ANTICLINE.

The city of Jackson is situated near the center of a broad, gentle fold, which shows a domelike arch in cross section from northwest to southeast, and a terrace-like form from northeast to southwest, as shown on Plate VIII. Near the southwestern and southern parts of the anticline the dips are steepest, as much as 60 to 70 feet to the mile; and in the northwestern and southwestern parts the dips are gentle, at a rate of 30 feet and less per mile. The northern extent of this fold has not been determined, and as Hilgard¹ has stated the beds are at least as high at Jackson as at Canton, 25 miles farther north. The beds are nearly horizontal in the intermediate area, but have possibly a slight northerly dip. Thus the fold is more strongly developed here than farther north, even if it continues beyond the area mapped. This development of the fold necessarily follows from its transverse position with regard to the dip of the beds which, if the deformation were equal at both ends, would make the elevation of the beds lower on the south.

From a short distance north of Jackson there is probably a slight dip northward toward Madison Station, although the exposures are

¹ Hilgard, E. W., *Geology and agriculture of Mississippi*, pp. 128-129, 1860.

not sufficient to determine its amount. This dip is evident from the presence of lower beds at Jackson than are exposed in the area to the north. Just where the southerly dip observed at Jackson flattens and is reversed in direction can not be accurately stated, but it is certainly only a short distance north of town.

The anticline is represented on the accompanying map (Pl. VIII) as more flat topped than it really is, because it is not possible, with the information available, to locate accurately the contours above 460 feet. That the fold in the area rises above that level is proved by the presence of the middle clay member of the Jackson at such an elevation on the hills that if the interval between its top and the top of the limestone be added the limestone would lie at about 500 feet. This proves that the fold is at least that high, but how much higher can not be stated, because the clay is uniform in lithology, and no key beds have been recognized in it.

There are two minor folds shown on the sides of the anticline that are of interest—one at Forest Hill School, which seems either to parallel the axis of the major fold or to be a continuation of it, and the other near Plain. Both are shown by slight deflections of the contour lines. The continuation of the one near Plain as a cross fold, passing northwest near Jackson, would account for the beds there being higher than farther north.

The general dip beyond the southern limits of the area contoured is southerly at the gentle rate of about 20 to 30 feet to the mile.

VICKSBURG AND ELDORADO MONOCLINES.

The folding west of Big Black River is much less pronounced and in a different direction from that near Jackson. Here the rocks are only slightly disturbed from their normal position, and, instead of having a general southerly dip over the entire area, the dip is accentuated at two places, forming monoclinal folds. In the intermediate area the rocks are practically horizontal, forming a structural terrace. Both these folds are more pronounced to the west, and they lose their individuality east of Big Black River in the long, gentle slope which forms the west limb of the Jackson anticline.

The downward bend of the strata which forms the Vicksburg monocline extends from Vicksburg northeast past Bovina to Big Black River, as outlined on Plate VIII. From this place the strata dip southward at an average rate of 18 feet to the mile, and the Vicksburg limestone gradually disappears under the overlying Catahoula sandstone.

North of this fold the beds remain flat for about 10 miles, forming a broad structural terrace which has a slight upwarp near its middle part. Beyond this level stretch the beds bend upward for a few

miles, forming the Eldorado monocline and flatten again. The crest¹ of this monocline extends from a point near Eldorado post office southeast toward Cox Ferry on the Big Black, where it is obscured by other folds to the east. (See Pl. VIII, in pocket, for exact location.) At the west end of the fold, as mapped, the dip to the south is about 25 feet to the mile from the crest of the monocline, and north of it the dip gradually lessens and the beds become horizontal and remain so to a point beyond Phoenix. The east end of the monocline is less pronounced and is obscured by other gentle folds to the east.

There are no exposures of the key rock in the area between Big Black and Yazoo rivers, and the contours are drawn across this area in the most direct way. The Vicksburg and Eldorado monoclines do not end abruptly at the bluffs on the east side of Mississippi and Yazoo rivers, but their western continuation can not be shown because of the absence of exposures in that direction.

MINOR STRUCTURAL FEATURES.

A fold of unknown form and magnitude is suggested by the contour lines near Brownsville. The exposures in that area have not been sufficiently studied to determine the exact character of the folding, which, however, may not be worth further investigation unless the main structures here outlined prove to be productive.

Another irregularity in the general dip of the rocks is found near Champion Hill. The Vicksburg limestone is exposed at about the same level near this station as it is 5 miles southwest on Jackson Creek, $1\frac{1}{2}$ miles above the place where it empties into Bakers Creek and $3\frac{1}{2}$ miles south-southeast of Edwards. The exposures here are not sufficient for an exact determination of the structure, which is believed to have the form suggested on the map (Pl. VIII, in pocket).

Near the middle of the broad structural terrace between the Vicksburg and Eldorado monoclines there is a low, gentle rise which dies out to the west and forms a projecting anticline from the larger fold to the east. The location of this anticline is only approximately shown, because of the absence of exposures over the area.

FAULTS.

Breaks in the strata, called faults, are not believed to be common in this area, and evidence of only two has been found; one occurs on Richland Creek, 5 miles southwest of Brandon, and the other on Pearl River, below Jackson.

¹ The line along which approximately horizontal strata are bent downward to form a monocline is called the crest of the monocline. It is analogous to the axis of an anticline. The position of such a line is different for each successive stratum. In this report the location of the crest is determined from observations on the top of the hard limestone of the Vicksburg.

One-half mile down Richland Creek from the crossing of the Brandon-Florence road a thick bed of Catahoula sandstone crosses the creek and dips at a high angle to the north. This outcrop is between two exposures of the Vicksburg on the same creek and appears to represent a part of the Catahoula exposed in the bluff of the creek near by. Its abnormal dip is believed to be due to a fault.

At Richmond Lake Bluff on Pearl River, $5\frac{1}{2}$ miles by air line below Jackson, a prominent exposure of bluish calcareous clay with thin layers of earthy limestone of Jackson formation dips at the abnormal rate of 5° – 6° S. This steep dip appears to continue for some distance downstream, and in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 10, T. 4 N., R. 1 E., near the upper end of Steamboat Bayou, 30 to 40 feet of the overlying sand is exposed. Here the river bottom contains numerous silicified logs, which appear to have weathered out of the sand, a bed in which they are abundant. Around the bend to the east the underlying gray calcareous clay is again found, thus suggesting that the abnormal dip above mentioned is due to an eastward-trending fault which has a downthrow on the north side that brings the "Madison sand" into contact with the underlying clay (Yazoo clay of Lowe). As further evidence of this break, one-third mile below the supposed fault a long exposure in the west bank of the river shows a number of small faults which have throws of a foot or less, with the downthrow on the north side. These faults are clearly shown by a thin layer of limestone in a clay bed. The general dip here is about normal.

POSSIBILITIES OF OIL AND GAS.

GENERAL CONSIDERATIONS.

The occurrence of oil and gas in commercial quantities depends on a number of factors, among which may be mentioned conditions favoring the formation of oil or gas, the presence of a porous stratum, or "sand," between two impervious layers to act as a reservoir, and favorable structure for accumulation.

Although it has been said that "the best indication of oil is a little oil," there are a number of the important fields in this country which showed no trace of oil prior to the tapping of the productive sand by the drill. This was true of the Caddo, De Soto and Red River, and Corsicana fields and, with the exception of salt domes, seems to be particularly true of Coastal Plain fields, where the gentle folds have not been greatly faulted, and where the soft shale and clay may seal those faults that are present so as to prevent leakage. Thus the lack of seeps of oil can not be used as a proof of its absence in the underlying strata. Drilling, moreover, has not been deep enough to throw any light on the subject, for nowhere in this area or in the neighboring region has even the horizon of the shallowest

oil-bearing formation of northwest Louisiana been reached. Thus the absence of direct evidence here, and the distance from the nearest productive fields in northwest Louisiana, leaves this question unsolved, although the similarity in the geology of the two regions encourages the belief that oil may occur here.

The presence of a porous stratum to serve as a reservoir for the accumulation of the oil is practically assured, as sands approximately the equivalent of those that are productive in Louisiana, the Ripley and Tuscaloosa, are known to dip under this region, although their depth and nature here are imperfectly known.

The structures here described, though not so pronounced as they are in some parts of the productive Coastal Plain fields, are more pronounced than in others, and in many ways similar to them. The Jackson anticline is believed to contain the most favorable area for the accumulation of oil and gas because of its similarity to anticlines in northwest Louisiana. Although it is not possible to point out as accurately as desired the most favorable locality on this fold for testing; a well located anywhere on it inside of the 460-foot contour would have a better chance of success than the average wildcat well located without regard to structure.

MOST PROMISING AREAS FOR PROSPECTING.

The prominent structural features of the area, as described under the heading "Structure" (pp. 108-112), are the Jackson anticline and the Vicksburg and the Eldorado monoclines. The most favorable areas for oil and gas accumulations lie in these folds, as stated in the following paragraphs.

JACKSON ANTICLINE.

As shown on Plate VIII (in pocket), the Jackson anticline is a broad, gentle, semicircular fold from which the rocks dip in three directions. Its northern extension is not known, and neither is the shape of its top, a feature of special significance in connection with the location of favorable areas for prospecting. The reasons for believing it is not as flat-topped as indicated on the map have been given. A gentle rise of the strata from the south edge of Jackson for about 2 miles north and the presence near the north edge of town of beds lower than any exposed farther north suggest the culmination of the fold near that place.

In the absence of definite knowledge regarding the exact form of the top of this fold there are two possible interpretations which are worthy of consideration because of their bearing on the possible accumulation of oil and gas: Either the fold has a well-defined axis from which the rocks dip gently but probably at an increasing angle or the top of the fold is flat and without a well-defined axis, and the dips become flatter above the 460-foot contour.

The evidence seems to indicate that the fold has a fairly well-defined axis, and that the anticline along this indefinite line is much higher than 460 feet. If minor folds cross this inferred axis, such cross folds would be eminently satisfactory as places to test the structure, for it is not believed that there are any synclines on the fold deep enough to trap the oil or gas and prevent migration to them. The best chance for success appears to be near the supposed axis, where the anticline is believed to be highest and where there is a suggestion of such a cross fold, as near the north edge of Jackson in sec. 34 or 26, T. 6 N., R. 1 E.

If the fold is flat-topped and the dip becomes decidedly flatter above the 460-foot contour, a favorable place to drill would be near this contour and at a place where the dip on the flank of the fold is shown to be steepest, as near Forest Hill School and near Clinton. A well about half a mile inside this contour and near these two places would probably be favorably located to test these areas and should at least make a showing if there are accumulations of oil or gas in the vicinity. Such tests might be made in the SW. $\frac{1}{4}$ sec. 14, T. 5 N., R. 1 W., near Forest Hill, and in the NE. $\frac{1}{4}$ sec. 29, T. 6 N., R. 1 W., near Clinton.

VICKSBURG MONOCLINE.

Oil accumulates in areas where there is a change in the rate of dip and under structural conditions similar to those shown to exist along the Vicksburg monocline, as outlined on the map (Pl. VIII, in pocket). This monocline extends from the southern edge of Vicksburg northeastward past Bovina to Big Black River near Askew Bridge, where it merges into the western slope of the Jackson uplift. The crest or upper axis of this fold parallels and practically coincides with the 120-foot contour, as the beds are flat north of it for a distance which is considerably greater at the western end than at the eastern. As the structure is more definitely located and is probably more pronounced at the western end, the most favorable location for prospecting is near Vicksburg and on or close to the crest of the monocline, which represents as accurately as can be shown the location of the downward bend of the strata. A belt a mile wide on each side of this line represents, according to the best information available, the location of possible productive territory.

ELDORADO MONOCLINE.

The Eldorado monocline is similar to the Vicksburg monocline in general features, though it differs principally in that it extends south of east instead of north of east. The crest of this fold, which represents the most favorable territory for prospecting, extends from a point near Eldorado toward Cox Ferry on Big Black River. Like the Vicksburg monocline, it shows larger dips at its west end,

as mapped, and offers more favorable conditions there for oil or gas to accumulate. This area probably could be tested best by wells located along the crest of the monocline, as shown on the accompanying map (Pl. VIII, in pocket), near Eldorado, for instance, in sec. 35 or 36, T 9 N., R. 5 W. Unless good indications of oil or gas were obtained from a well here, further prospecting on this monocline would probably not be justifiable.

DEPTH TO POSSIBLE OIL AND GAS BEARING FORMATIONS.

A list of formations into which the rocks of the Vicksburg-Jackson area have been divided is given in the table on page 97. Of these the upper part of the Claiborne and overlying formations are known at the surface and are described on pages 97-108. The formations below the Claiborne are known from well records and surface outcrops outside of this area. The best available information as to the character and thickness of the different formations is summarized in the table on page 97, but for the benefit of the driller this information is elaborated in the following pages. The formations will be discussed in the order in which they are penetrated in a well, so that they may be followed and compared easily with the well record.

The following table shows the succession of formations of northwest Louisiana and their approximate equivalents in Mississippi. The correlation here suggested is true in only the most general way, as these formations, especially those of the Cretaceous, represent different time intervals at different places in Mississippi.

Partial section of Cretaceous and Tertiary formations of Mississippi and Louisiana.

Geologic age.	Mississippi.	Northwestern Louisiana.
Eocene.	Claiborne group.	Claiborne group.
	Wilcox group.	Wilcox formation.
	Midway group.	Midway formation.
Upper Cretaceous.*	Ripley formation.	Arkadelphia clay. Nacatoch sand.
	Selma chalk.	Marlbrook marl. Annona chalk. Brownstown marl.
	Eutaw formation.	Eagle Ford clay.
	Tuscaloosa formation.	Woodbine sand.

* The correlations here suggested were made by L. W. Stephenson, who states that they are approximately true if a section along an east-west line through Okalona, Chickasaw County, Miss., is compared with that of northwest Louisiana.

In Louisiana oil and gas are found in the Nacatoch, in the upper part of the Eagle Ford, called the Blossom sand member, and in the base of the Eagle Ford or in the Woodbine sand, the reservoir of the deep oil and gas of Caddo Parish. The corresponding formations in Mississippi, the Ripley, Eutaw, and Tuscaloosa, are the most promising formations of the Vicksburg-Jackson area, not only because they are of approximately the same age as the productive formations of Louisiana and were deposited under similar conditions but also because they are composed largely of sand and are therefore capable of storing oil and gas.

In the oil fields of northwest Louisiana the Wilcox outcrops, and the productive formations are nearer the surface than in this area, where the Jackson and Vicksburg formations outcrop. In the vicinity of Jackson the Claiborne is near the surface, and is exposed over a small area. At its outcrop farther to the northeast it has an estimated thickness of about 500 feet and across Mississippi River in Louisiana it has a thickness, based on well records, of about 1,500 feet. This shows a rapid rate of thickening in that direction and indicates that this formation is considerably thicker at Vicksburg than at Jackson. In well records these beds are distinguished with difficulty, on the basis of their lithology, from the Wilcox beds below. The marine character of the Claiborne, as shown by the presence of fossil shells, and the generally nonmarine character of the Wilcox, however, should make the separation possible, even in well records. In its upper part the Claiborne consists of lignitic clays and sands, which are reported to have a thickness of 418 feet at Jackson (see p. 98); below are marine marls and calcareous sands and finally several hundred feet of sandstones, quartzites, and clay stones. The Claiborne contains fresh water in the neighboring area to the north and will probably be found barren of oil and gas here.

The Wilcox has been reached probably in only one well in this area—in the well at the Edwards House in Jackson. This well has a depth of 1,446 feet and yields a strong flow of salty water with a small showing of gas. So far the Wilcox has not yielded oil and gas in commercial quantities, but it has made showings of gas at a number of places and should be carefully watched when being drilled through. Its thickness is variously estimated from 850 to 1,500 feet, but it is probably not greater than 1,000 feet. Its upper and lower parts are very similar in composition and consist of lignitic clay and some sand; its middle part is dominantly sandy. In the region near Jackson the depth to the base of the Wilcox is estimated to be about 2,000 to 2,500 feet.

Below the Wilcox are the marine beds of clay, sandstone, limestone, and marl of the Midway group, which have a thickness of several hundred feet. In drilling these beds should be distinguished

from the overlying Wilcox by the difference in the rocks and by the presence of marine fossils. The composition of the Midway is such that it should serve well as an impervious cap for the Ripley sands below.

The Ripley formation contains large amounts of sand at its outcrop, and though its composition in this area is believed to be similar, it may be represented here by chalky limestone similar to that composing the Selma chalk. If found to contain sand it should be thoroughly tested, as it represents approximately the horizon of the Nacatoch sand, which yields the shallow gas and heavy oil in northwest Louisiana. It can probably be reached in the vicinity of Jackson between 2,500 and 3,000 feet.

Below the Ripley is the Selma chalk, which is roughly the equivalent of the "chalk" of northwest Louisiana and is similar to it in character. It should be an easily recognized formation in wells, as it differs strikingly from the formations both above and below. This formation has a measured thickness of 930 feet in a well at Livingston, Ala., where it consists of sandy and argillaceous chalky limestone.

The Eutaw formation, which lies below the Selma chalk, is composed chiefly of sand in the area of its outcrop and is believed to retain this sandy character in the Vicksburg-Jackson area, at least sufficiently to furnish a reservoir for the accumulation of oil and gas. Unless the overlying formations in this area are thinner than expected the Eutaw is the deepest formation that can be reached easily by the drill, if, indeed, it is not beyond easy reach. On the basis of the estimates referred to above it will be reached near Jackson at about 3,500 or 4,000 feet. This formation is in part the equivalent of the Eagle Ford formation of Louisiana and may contain beds which are of the same age as the deep oil and gas bearing beds of that region, although the Eutaw is generally considered somewhat younger than the Eagle Ford.

The estimates given above apply to the vicinity of Jackson; at the Vicksburg and Eldorado monoclines the depths to the various formations are greater, probably as much as 500 feet or even more, owing to the presence of higher beds of Jackson and Vicksburg age and to the thickening in that direction of the Claiborne and possibly also the Jackson. The depths in the valley bottoms at the Eldorado monocline are somewhat less, about 80 feet, than at the Vicksburg monocline, if there is no variation in the thickness of the underlying beds between the places. At best these estimates are only approximations, as they are based on somewhat uncertain estimates of the thickness of the formations at their outcrop some distance away. As it seems more likely that the formations increase in thickness from their outcrop in this direction rather than decrease, the maximum depths were estimated so as to allow for a moderate amount of thickening.

SUGGESTIONS TO DRILLERS.

That a single hole is not sufficient to condemn any considerable area around it has been demonstrated in the history of a number of oil fields, particularly in those in which there are minor structural features and local variations in thickness and porosity of sands, which cause the productive area to be "spotted." However, as deep drilling is expensive, a wildcat well should be so managed as to give the greatest amount of information, not only as to the presence or absence of oil under a particular tract of land, but as to whether the general underground conditions are favorable to the occurrence of oil in that vicinity.

To test this area adequately a deep hole must be drilled, and the hole should be bailed to test all the sands that are promising. This will require a large initial hole in order to accommodate successively smaller casings. The sands of the Ripley and Eutaw formations should be most carefully watched and tested by bailing, for a hole full of water heavily charged with mud may obscure or entirely hide traces of oil. Even a trace of oil in this area, which is so far from productive territory, may be of great importance in deciding which is the most promising sand and whether further drilling is justified.

An accurate log of the well should be kept, with samples of cuttings from each 20 feet, or less if the formation changes. Fossil shells should be carefully preserved, with a record of the depth from which they were obtained, for study by a specialist. By this means the different formations penetrated may be recognized and the position and thickness of the sands, and their relationship to known productive sands, may be determined. This information may aid materially in locating small isolated pools or the presence of oil in other parts of the folds.

WELL LOGS.

The following well logs indicate the general character of the formations in the Vicksburg-Jackson area:

Log of well of Kimberly-Wing Co., Cedars, Miss.

[Layne & Bowler Co., contractor and driller. Completed Dec. 28, 1910.]

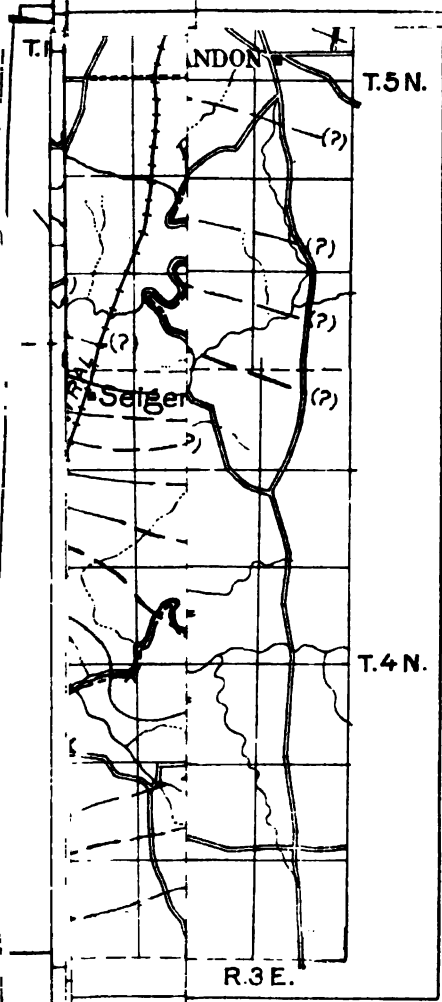
	Thickness.		Depth.	
	<i>Ft.</i>	<i>in.</i>	<i>Ft.</i>	<i>in.</i>
Top soil and red clay.....	25	0	25	0
Vicksburg limestone:				
Blue clay.....	10	0	35	0
Sands, fine.....	29	0	64	0
Rock (limestone).....	3	3	67	3
Gumbo.....	1	3	68	6
Rock.....	1	3	68	9
Gumbo.....	1	4	70	1
Rock.....	1	3	71	4
Gumbo.....	2	6	73	10
Rock.....	1	9	75	7
Gumbo.....	11	9	87	4
Rock.....	1	10	89	2
Gumbo.....	1	0	90	2
Rock.....	2	9	92	11
Gumbo.....	1	11	94	10
Rock.....	10		95	8
Gumbo.....	5		96	1
Rock.....	8		96	9
Gumbo.....	10	3	107	0
Rock.....	4	4	107	4
Gumbo.....	47	8	155	0
Jackson formation:				
Sand, fine.....	40	0	195	0
Gumbo.....	595	0	790	0
Chalborne group:				
Sand.....	106	0	896	0
Gumbo.....	4	8	900	8

Log of city well at Edwards, Miss.

[Layne & Bowler Co., contractor and driller.]

	Thickness.	Depth.
	<i>Ft. in.</i>	<i>Ft. in.</i>
Red clay.....	58 11	58 11
Vicksburg limestone:		
Blue clay.....	55 6	114 5
Rock (limestone).....	4 8	119 1
Soapstone.....	2 0	121 1
Rock (limestone).....	2 0	123 1
Soapstone.....	3 8	126 9
Rock (limestone).....	1 4	128 1
Soapstone.....	3 0	131 1
Rock (limestone).....	1 10	132 11
Soapstone.....	6 2	139 1
Rock (limestone).....	7 5	146 6
Packed sand.....	1 0	147 6
Rock (limestone).....	1 6	149 0
Packed sand.....	22 1	181 1
Jackson formation:		
Gumbo.....	39 5	220 6
Sand, muddy, packed.....	26 10	247 4
Soapstone.....	3 9	251 1
Gumbo, sandy.....	41 4	292 5
Gumbo, blue.....	15 0	307 5
Sand, dry, packed.....	23 10	331 3
Rock, hard sand.....	19 9	351 0
Sand, hard, dry, floating.....	15 0	366 0
Gumbo.....	4 7	370 7
Sand, hard, dry floating.....	9 0	379 7
Gumbo.....	339 10	719 5
Undifferentiated Jackson and Claiborne:		
Sand.....	4 6	723 11
Gumbo.....	21 9	745 8
Sand.....	4 0	749 8
Gumbo.....	79 8	829 4
Sand.....	4 0	833 4
Rock.....	2 0	835 4
Sand.....	3 0	838 4
Gumbo.....	27 10	866 2
Claiborne group:		
Gumbo, chocolate-colored.....	33 6	899 8
Marl, brown.....	18 6	918 2
Sand rock.....	1 0	919 2
Soapstone.....	10 0	929 2
Sand, fine, packed.....	15 5	944 7
Gumbo, hard, sandy.....	47 10	992 5
Sand rock, very hard.....	23 5	1,015 10
Gumbo, sandy.....	15 0	1,030 10
Sand rock.....	16 6	1,047 4
Gumbo, chocolate-colored.....	16 8	1,064 0
Sand rock.....	46 4	1,110 4
Gumbo, sandy.....	3 8	1,114 0
Sand, very hard, packed.....	13 7	1,127 7
Sand, packed.....	19 9	1,147 4
Sand, very hard, packed.....	9 0	1,156 4
Clay, soft, yellow.....	9 0	1,165 4
Sand, packed.....	15 0	1,180 4
Clay, sandy.....	3 5	1,183 9

N 641 PLATE VIII



JGS

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DEPARTMENT OF THE INTERIOR

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UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 641—E

AN ANTICLINAL FOLD NEAR BILLINGS
NOBLE COUNTY, OKLAHOMA

BY

A. E. FATH

Contributions to economic geology, 1916, Part II

(Pages 121-138)

Published July 15, 1916



WASHINGTON

GOVERNMENT PRINTING OFFICE

1916

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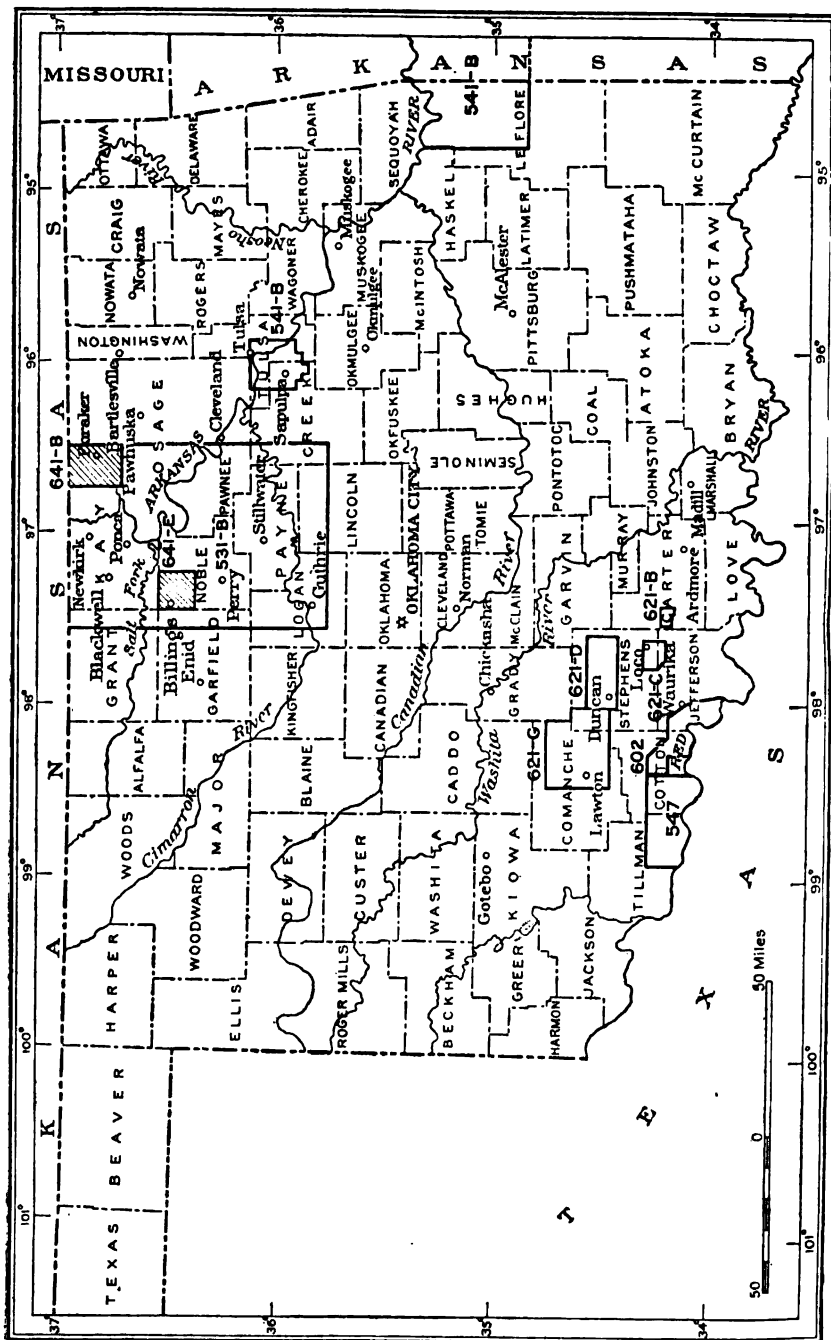


FIGURE 1.—Index map of Oklahoma showing location of Billings region (marked "641-E"). The districts indicated by heavy lines have been described in separate papers, the numbers of which appear in black type.

AN ANTICLINAL FOLD NEAR BILLINGS, NOBLE COUNTY, OKLAHOMA.

By A. E. FATH.

INTRODUCTION.

INCENTIVE FOR INVESTIGATION.

During February, 1916, gas was struck in small quantities at shallow depths in a well being drilled by the Mid-Co Petroleum Co. a few miles southeast of Billings, Noble County, Okla. As this discovery was made at a place more than 20 miles distant from any other known oil and gas development it has attracted considerable attention, which is justified by the presence of a large anticlinal fold, a type of structure that should be favorable for the accumulation of oil and gas. A description of the anticlinal fold and a discussion of the possibilities of developing an oil and gas field here are given in this brief report, which is based on a rapid examination of the region made late in February and early in March, 1916.

LOCATION, ACCESSIBILITY, AND CULTURE.

The anticlinal fold to be described lies in the northwestern part of Noble County, Okla. (See fig. 1, p. iv.) It may extend northward into Kay County, but the scarcity of rock outcrops made it impossible to verify this supposition in advance of sufficient drilling to determine the underground structure.

The town of Billings, which is at the terminus of a branch line of the Chicago, Rock Island & Pacific Railway running from Enid, is the nearest shipping point. Bliss and Red Rock are near-by towns on the Atchison, Topeka & Santa Fe Railway, which runs a short distance east of the area shown on the accompanying map (Pl. IX). Perry, the county seat of Noble County, is 9 miles to the south, at the intersection of the Atchison, Topeka & Santa Fe and the St. Louis & San Francisco railroads. The region of the anticline can be reached from any of these towns.

The surface of the area is in general a gently rolling prairie but is modified here and there by low escarpments where the more resistant beds have withstood erosion better than the adjacent softer beds. The region is almost devoid of timber except along the stream

valleys. Most of it is under cultivation and it contains many good farms. The roads follow the section lines and most of them are sufficiently good for automobile travel.

METHODS OF FIELD WORK.

For lack of time a detailed map of the entire region was not made, but it is believed that the more important anticlinal features were determined with considerable accuracy. The structure contours on the map (Pl. IX) are based on elevations and locations determined by means of plane table, telescopic alidade, and stadia rod. Such structure contours show how the rock beds lie. They usually refer to some particular bed and represent the elevations or altitude above some datum plane at which this bed may be found. Where the bed has been worn away they represent the elevations at which it lay before it was removed. The elevations shown on Plate IX are based on a bench mark established by B. F. Lewis, surveyor of Garfield County, at the southwest corner of sec. 19, T. 24 N., R. 2 W., and described as a spike in a telephone pole at the northeast corner of the road intersection, elevation 1,036.31 feet. This bench mark is based on the elevation of a United States Geological Survey bench mark at Enid, Okla. At several places where lack of time did not permit accurate plane-table determinations of strike and dip the approximate strike and dip as observed by the writer are shown on the map (Pl. IX) by the ordinary strike and dip symbol.

ACKNOWLEDGMENTS.

The writer is indebted to many individuals and companies for information and suggestions, and desires to express especial obligations to Valerius, McNutt & Hughes, Julius Fohs, Frank B. Van Horn, L. E. Trout, and the drillers of the Mid-Co Petroleum Co.'s well.

GEOLOGY.

STRATIGRAPHY.

The surface rocks of the region have an aggregate thickness of more than 150 feet and are predominantly shale, but include also sandstone and argillaceous limestone, all of Permian age. The position of these rocks in the Permian series is roughly estimated at 500 to 900 feet above the horizon of the Neva limestone, which is generally placed near the top of the underlying Pennsylvanian series. No single outcrop shows the complete succession of rocks exposed in the region, and hence to obtain the following stratigraphic section it was necessary to combine parts of the section measured at three localities.

T.24 N

GARFIELD COUNTY
NOBLE COUNTY

T.23 N

*Composite section of exposed rocks measured in the Billings region.*Section exposed in the NW. $\frac{1}{2}$ sec. 23, T. 23 N., R. 2 W.

	Ft.	in.
1. Sandstone, reddish brown, cross-bedded, ripple marked; thickness variable-----	3±	
2. Shale and thin sandstones, poorly exposed, probably reddish to chocolate-brown in color-----	19	0
3. Sandstone, reddish brown, thin bedded, poorly exposed-----	1±	
4. Shale, reddish chocolate-colored-----	5±	
5. Limestone, composed of angular limestone particles-----		3
6. Shale, gray; contains four thin limy layers in upper 2 feet-----	5	3
7. Limestone, argillaceous, light gray-----		1
8. a. Shale, gray to reddish chocolate-colored, about-----	6±	
b. Shale, gray; near middle contains a 4-inch layer of concretions as much as 2 inches in diameter-----	3	9
9. Limestone, argillaceous, light gray-----		2
10. a. Shale, gray-----		1
b. Shale, mottled greenish gray and red, limy near top-----	5	0
11. Limestone, argillaceous, light gray; thickness variable-----		6-10
12. a. Shale, gray-----		4
b. Shale, chocolate-colored-----	2	0
13. Limestone, argillaceous, light gray-----		2±
14. a. Shale, reddish gray-----		11
b. Shale, reddish chocolate-colored; base not exposed-----	3+	
c. Poorly exposed; probably all shale-----	9±	

Section exposed in the NW. $\frac{1}{2}$ sec. 14, T. 23 N., R. 2 W.

15. Sandstone, dark red, cross-bedded; contains plant remains; thickness variable-----	1-5	0
16. a. Shale, gray-----	5±	
b. Shale, maroon-----	1	0
c. Shale, gray-----	5	0
17. Limestone, argillaceous, light gray, thin bedded; weathers out in small angular fragments-----		8
18. Shale, gray, limy near top-----		9
19. Limestone, argillaceous, light gray-----		3
20. Shale, gray-----		3
21. Limestone, argillaceous, light gray-----		3
22. Shale, gray-----		6
23. Limestone, argillaceous, light gray, rather massive; contains mud cracks-----		8
24. a. Shale, limy, and argillaceous limestone; in beds $\frac{1}{2}$ inch to 3 inches thick; limestone light gray and shale dark gray-----	2	0
b. Shale, not well exposed but probably gray-----	6	8

	Ft.	In.
25. Limestone, argillaceous, light gray; contains thin lenses of gray shale; lowest bed 2½ inches thick and contains many shells of the bivalved crustacean (<i>Estherea</i> cf. <i>E. minuta</i>). At some localities this bed is sandy-----		6
26. a. Shale, gray to greenish gray-----	1	9
b. Shale, dark gray, almost black-----		9
c. Shale, gray to yellowish gray-----	7	0
27. Limestone, argillaceous, thin bedded; weathers out in small fragments; contains thin lenses of gray shale-----	1	2
28. a. Shale, dark gray-----	1	1
b. Shale, gray, more resistant near bottom and top than in middle-----	2	6
c. Shale, gray to greenish gray-----	5	3
29. Limestone, light gray, thin bedded, weathers out as small slabs or plates; shows some cross and wavy bedding; contains thin lenses of gray shale..	1	6

Section exposed in the NW. ¼ sec. 22, T. 23 N., R. 2 W.

30. a. Shale, yellowish gray-----	5	0
b. Shale, mottled gray and reddish gray-----	2	0
c. Shale, bluish gray-----	3	0
d. Shale, very limy-----		1
e. Shale, gray-----	5	6
f. Shale, mottled greenish gray and reddish brown..	2	6
g. Shale, gray, contains three thin limy layers, one 7 inches, another 13 inches, and the other 13 inches below the top-----	6	0
h. Shale, reddish chocolate-colored-----	1	10
i. Shale, gray-----	3	2
j. Shale, very limy, light gray-----		2
k. Shale, gray, contains one thin limy layer 3 inches above bottom-----	2	9
l. Shale, reddish brown-----	5	6
m. Shale, gray, base not shown-----	3+	
	154	6+

The three most conspicuous of these strata were used as key beds in determining the details of the structure. These key beds are No. 29 of the section, which is the lowest limestone bed; No. 15, which is the sandstone bed near the middle of the section; and Nos. 1, 2, and 3, the group of sandstones at the top. The structure contours on the map show the position and elevation of bed No. 29, the lowermost limestone, which is generally very thin bedded and weathers out as thin plates or slabs. Where these characteristics are not pronounced or the outcrop is poor the bed can usually be identified by the presence of the less prominent but fossiliferous limestone bed (No. 25) about 20 feet above it. The sandstone beds of the section usually form prominent ledges and can generally be distinguished from one

another. The lowermost bed of sandstone (No. 15) ranges in thickness from a few inches to 5 feet and can be distinguished from the upper bed by its association with the thin limestones beneath rather than by any inherent characteristics of its own. The upper sandstones can be identified by the presence immediately beneath them of a considerable thickness of associated chocolate-colored shale. These associations are not uniformly persistent, but by a study of the section in the field the beds can usually be discriminated.

STRUCTURE.

GENERAL FEATURES.

The rock beds of northeastern and north-central Oklahoma generally dip to the west or the northwest, and in north-central Oklahoma the average dip at different places ranges from 25 to 50 feet to the mile. Wherever the dip to the west is typically developed the place is unfavorable for finding oil and gas. Oil and gas are more likely to be found at places where the rocks have been warped or folded and the beds either lie flat or dip to the east. The size and value of the more productive oil fields of Oklahoma depend almost directly on the areal extent of the folds and the amount of their dip to the east, and if these are here the controlling features, the anticlinal fold herein described, which resembles that of the developed oil fields in Oklahoma, should be favorable to the accumulation of oil and gas in this region.

The anticlinal fold in this area trends in general northeastward and occupies parts of at least Tps. 23 and 24 N., Rs. 1 and 2 W. As there are few outcrops its exact magnitude and extent can not be fully determined, but sufficient data are at hand to indicate its general shape and size. The scattered rock outcrops show that the anticlinal fold has at least two parts, an elongated dome to the southwest and a broad anticline to the northeast.

THE DOME.

Near the center of T. 23 N., R. 2 W., the anticlinal fold is narrower and its sides are steeper than elsewhere, as is shown by the rock beds, which are excellently exposed here. This local feature is oval and may be called a short anticline or, preferably, an elongated dome.

Unlike many other anticlines and domes in Oklahoma, whose forms can be determined only by painstaking work or by doubtful correlation of beds, this dome is so well exposed that it can be readily seen even by the layman. The structure can be observed to the best advantage by looking south and west from the northeastern part

of sec. 15, T. 23 N., R. 2 W.; and by looking west, north, and east from the top of the escarpment near the center of the northern part of sec. 22 of the same township. From the first point of observation the crest of the fold may be seen near the north quarter corner of sec. 22, where the beds in the escarpment are practically flat. The dip to the east may be seen in the escarpment east of this crest and can be followed into the west side of sec. 14. From the second point of observation the thin limestone beds can readily be seen descending both to the east and the west from the crest of the dome.

The highest part of the dome is in the south-central part of sec. 15. As before mentioned, the dome is oval and appears to extend southwestward into the SE. $\frac{1}{4}$ sec. 21 and northeastward into the SE. $\frac{1}{4}$ sec. 10. The southeast dip on the dome persists for at least a mile, and in this distance the beds descend in elevation more than 130 feet. Exactly how far this dip to the southeast persists is not known, for the rock outcrops are insufficient to permit its determination farther.

On the northwest side of the dome the beds dip away steeply for a mile or more before they resume the normally gentle westward dip of the region.

The southwestern termination of the dome appears to be in the NE. $\frac{1}{4}$ sec. 28, although this assumption could not be definitely proved. It seems probable that the sandstone which crops out in the road about a quarter of a mile east of the southwest corner of sec. 22 is the lowest sandstone bed (No. 15 of the section on pp. 123-124). The sandstone exposed a few hundred feet north of the south quarter corner of sec. 22 is almost certainly the highest sandstone bed (No. 1) of the section. Less certainly, but probably, the sandstone exposed in the center of the SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 27 and the residual sandstone near the center of the NE. $\frac{1}{4}$ sec. 28 are from this same bed. Whether or not the slope of the surface in the SW. $\frac{1}{4}$ sec. 22 and the SE. $\frac{1}{4}$ sec. 21 represents roughly the position in which the underground rock beds lie (dip slopes) can not be certainly determined, but the position of the few scattered outcrops just mentioned seems to lend some basis for this assumption.

The dip of the beds in the NW. $\frac{1}{4}$ sec. 15 is almost north and indicates that the dome is lower in the northern part of this section than farther south. The structure here could not be exactly determined for lack of outcrops, but it is probable that a "low" or "saddle" in the anticlinal axis in this locality marks the northeastern termination of the dome.

THE ANTICLINE.

The northern and apparently the larger part of the Billings anticlinal fold can not be so fully nor so readily distinguished because of insufficient rock outcrops. It is a broad fold at least 5 miles

wide and can be traced with certainty northeastward for about 7 miles. It narrows abruptly at its southern extremity, where it is connected with the dome to the southwest by a "low" or "saddle." Its sides are poorly outlined by two belts of scattered outcrops—an eastern belt, in which the beds dip to the southeast and which extends from the SW. $\frac{1}{4}$ sec. 23, T. 24 N., R. 1 W., to the NW. $\frac{1}{4}$ sec. 16, T. 23 N., R. 1 W., and a western belt, in which the beds dip to the west and which extends from the SW. $\frac{1}{4}$ sec. 31, T. 25 N., R. 2 W., to the NW. $\frac{1}{4}$ sec. 3, T. 23 N., R. 2 W. The eastern limit of the eastward-dipping beds was determined at but one place—in the SE. $\frac{1}{4}$ sec. 22, T. 24 N., R. 1 W. On the northeast there are no outcrops that indicate the character and location of that end of the anticline. The axis of the fold is indistinctly indicated at one place; it appears to cross secs. 30 and 31, T. 24 N., R. 1 W., in a northeasterly direction.

In the belts of outcrops mentioned above, the beds exposed are the same as those in the dome to the southwest, and they can be recognized with comparative ease. The almost complete absence of rock outcrops in the northern part of T. 24 N., R. 1 W., leaves the attitude of the northeast end of the anticline a matter of conjecture only. Whether the beds north of secs. 22 and 23, T. 24 N., rise rapidly and resume the normal westward dip, thereby terminating the anticline within this township, or whether they continue to strike northeastward and thereby extend the anticline to the township and county to the north can not be determined. The presence of the broad, silt-covered valley of Salt Fork River would appear to preclude any possibility of finding the northeast end of the anticline in the township on the north, as even the upland on the south contains practically no outcrops.

In the area embraced by the two belts of outcrops that outline the southeastern and northwestern flanks of the anticline there are a few scattered outcrops that expose beds of shale and thin beds of sandstone. These were not traced from place to place, and their exact position with reference to the beds of the measured section on pages 123-124 is not known, but they lie below the limestone-bearing series shown in the section. The strike and dip at several of these outcrops are more or less apparent, and the writer's observations are shown on the map (Pl. IX) by strike and dip symbols. An accurate determination of the strike and dip was made instrumentally in the SE. $\frac{1}{4}$ sec. 31, T. 24 N., R. 1 W., and these are shown on the map by a few short contours. A dip of 18 feet in 500 feet, or at an angle of about 2° , was measured by hand level and pacing in a "wash" in the SW. $\frac{1}{4}$ sec. 32, T. 24 N., R. 1 W. The direction of this dip was measured on a line trending S. 72° E. The exact strike of the beds was not determined. These observations, together with the attitude of the beds in the southeastern belt of outcrops men-

tioned above, indicate a dip to the southeast in a zone that averages more than three-quarters of a mile in width. This southeastward dip doubtless extends in both directions, but how far can not be determined. The amount of dip can also not be determined with any certainty. Estimates of the amount of dip to the southeast by different geologists would probably differ considerably. To the writer, 100 feet would be a low estimate; he would rather consider it equal to or even greater than that of the east dip on the dome, which, measured at one place, was about 130 feet.

The strong dip to the southeast observed in the SW. $\frac{1}{4}$ sec. 32, the dip to the south measured in sec. 31, and the probable dip to the west observed in the east-central part of sec. 36 and the NE. $\frac{1}{4}$ sec. 25, T. 24 N., R. 2 W., indicate that the crest of the anticline probably crosses secs. 30 and 31.

The eastern limit of the easterly dip was determined at one place, in the southeastern part of sec. 22, T. 24 N., R. 1 W., for in sec. 23 of the same township the dip is to the west. The axis of the syncline thus formed by the convergence of eastward and westward dipping beds can probably be followed southward, but the poor outcrops in this locality would necessarily make the work slow and uncertain.

A study of the structure contours shows that the anticline pitches to the southwest. The rise of the anticline to the northeast may produce either a broadening or a flattening of the structure in this direction. If it flattens, the northern extension of the dip to the east may terminate in T. 24 N., R. 1 W., and the beds may there resume their normal dip to the west. If the anticline does not flatten but continues northeastward, it probably extends northward to T. 25 N., R. 1 W. The drill will no doubt at some time furnish much of the information which is now lacking because of the absence of rock exposures.

DEVELOPMENT.

The well in which the original discovery of gas in the Billings region was made was drilled by the Mid-Co Petroleum Co. It is on the W. Hoover farm, near the center of the north line of the SW. $\frac{1}{4}$ sec. 22, T. 23 N., R. 2 W., and is high on the dome. The mouth of the well is about at the horizon of bed 24 of the stratigraphic section given on pages 123-124. Up to May 8, 1916, drilling had reached a depth of about 1,570 feet.

After the discovery of gas in the dome, the Humphreys Petroleum Co., according to press reports, started two wells¹ on the anticline. One of these is located on the Fred Murray farm, in sec. 17, T. 24 N., R. 1 W., and the other is in sec. 20, T. 24 N., R. 1 W. A depth of about 500 feet has been reported for the one in sec. 17.

¹ The reported locations of these wells were received too late to be incorporated on Plate IX.

OIL AND GAS SANDS.

The Mid-Co Petroleum Co.'s well, which is on the dome, has encountered seven gas sands (see log on p. 133) at depths of 570-582, 740-755, 830-842, 860-870, 880-905, 1,027-1,047, and 1,476-1,545 feet. Each sand encountered increased the production, and, according to the trade journals, the well is now capable of producing several million cubic feet of gas a day.

The Humphreys Petroleum Co.'s well in sec. 17, T. 24 N., R. 1 W., is reported to have struck a gas sand at a depth of 470 feet. Whether or not this gas sand is the same as the highest sand in the Mid-Co Petroleum Co.'s well is not known.

The finding of gas sands in the Mid-Co well shows that the dome is favorable for the accumulation of gas, even at shallow depths. The quantity of gas found in the Humphreys test on the anticline was not reported. Its presence, however, is encouraging, and would seem to indicate that the anticline also contains paying quantities of gas.

In any further discussion of the possibilities for finding additional oil and gas sand in this or any other region the relation of the area to all the near-by oil and gas producing region should be considered. Three such regions must be considered in relation to the Billings anticlinal fold. Located with reference to the Mid-Co Petroleum Co.'s well, they are the Blackwell oil and gas field, about 30 miles to the north; the Ponca City oil and gas field, about 21 miles to the northeast; and the area in which the Watchorn & Fortuna Oil Co.'s gas wells were recently drilled, 23 miles to the east.

The Watchorn & Fortuna Oil Co.'s first well, in so far as the well record (see p. 134) shows, encountered no oil and gas sands until it reached a depth of 1,990 feet. Twenty-five feet below this depth—that is, at a depth of 2,015 feet—it encountered its main flow, which yielded an initial production of over 35,000,000 cubic feet of gas a day. If this prolific gas sand extends northwestward it should have been penetrated by all the deep wells in the Ponca City field. As far as the writer is aware no prolific gas sand has been reported at Ponca City at a depth of 2,000 to 2,300 feet, where this sand should be found.

In the Ponca City field, northeast of the Mid-Co Petroleum Co.'s well, there are several shallow gas sands and three deeper oil sands, at depths of about 975, 1,330, and 1,550 feet. The two lower are the only productive oil sands.¹ These oil sands or closely related sands are either barren or absent in the region of the Watchorn & Fortuna Oil Co.'s wells. Records of two Ponca City wells are given on pages 134-136.

¹ Ohern, D. W., and Garrett, R. E., The Ponca City oil and gas field: Oklahoma Geol. Survey Bull. 16, pp. 28-29, 1912.

In 1911 a dry hole was drilled on the 101 Ranch, in sec. 25, T. 25 N., R. 1 E., which is 3 miles nearer to the Mid-Co Petroleum Co.'s well than the Ponca City field. The log of the drilling is given on page 136.

In the Blackwell field, in Kay County, north of the area here discussed, there are many gas sands, both shallow and deep, and one deep producing oil sand, from which some wells have had initial productions of over 1,000 barrels a day. Logs of two wells in this field are given on pages 137-138. The Blackwell field is 13 miles distant from the Ponca City field. The two fields are similar in respect to the presence of numerous shallow gas sands. The oil sands of the Ponca City field are either gas bearing, barren, or absent at Blackwell, where it might be expected that they would be found 100 to 400 feet lower than at Ponca City. Similarly, the deep oil and gas sand at Blackwell is either absent or nonproductive in the wells that penetrate its horizon at Ponca City.

As far as it has been developed, the dome in the Billings region is similar to the Ponca City and Blackwell fields in respect to the presence of numerous shallow gas sands. It appears, however, that the producing sands at Blackwell, at Ponca City, or in the Watchorn & Fortuna Oil Co.'s wells, in sec. 33, T. 23 N., R. 3 E., and sec. 4, T. 22 N., R. 3 E., are not of the persistent type, such as the Bartlesville and other sands found farther east in the State. Because of this apparent nonpersistency, especially of the more prolific oil sands, the probability that these particular sands will be productive in the Billings region seems small. However, the fact that the oil sands are more or less local in extent gives hope that local oil sands will also be found in the Billings region.

If any of the producing sands at Blackwell persist southward into the Billings region and are there capable of producing either oil or gas, it is the writer's opinion, which, however, is not based on field work done between the two areas, that, unless there is a considerable change in the thickness of the beds in the intervening area, the sands should be found at practically the same depth with reference to sea level in the two fields, which appear to be almost in line with the regional strike of the rocks. In like manner the producing sands of the Ponca City field should lie 200 to 500 feet lower in the Billings region than at Ponca City, and the gas sand of the Watchorn & Fortuna Oil Co.'s wells should lie 300 to 600 feet lower.

The areal extent of a commercial oil or gas pool depends directly on the richness of the sands and inversely on the depth at which the oil or gas is found. The deeper the sands the richer must the production be to put the wells on a commercial basis. The deepest known producing sands in north-central Oklahoma are in the Black-

well field, at a depth of about 3,300 feet. There is no apparent reason why oil or gas bearing sands may not exist in the Billings region at the same or even greater depths than at Blackwell, and for this reason a favorably located deep test well should be drilled there at some future time. If highly productive sands are found at shallow depths such a deep test will naturally be deferred until it seems advisable to look for additional producing sands.

RELATIVE VALUES OF THE PROSPECTIVE OIL AND GAS LANDS.

The region discussed in this report is probably all under lease by oil and gas companies, and it is therefore believed that the dome and anticline will be thoroughly tested. The insertion here of any statement as to the value of different parts of the region for drilling will probably not seriously influence any plans for development, but inasmuch as this report is for the benefit, not only of geologists and oil and gas producers, but also of the general public and those unfamiliar with the interpretation of geologic structure with reference to oil and gas, a few notes are given. It is a generally accepted fact that only the drill can determine the exact oil and gas value of any piece of land. For this reason the following discussion of land values must be tentative and suggestive only. It is based entirely on geologic structure and the fact that the rocks underlying the region are yielding commercial quantities of oil and gas in localities near by, these being the only factors governing the occurrence of oil and gas that can be determined by a study of the surface of the region. It must also be understood that other geologists may arrive at different conclusions from those here presented, and inasmuch as any such conclusions are more or less theoretical, all of them may carry equal weight.

Until drilling has definitely demonstrated the relative value for oil and gas of the different land units in the field, the crests of the dome and the anticline must be assumed to be the most valuable. The land lying immediately adjacent to the crests ranks next to them in value. Farther from the crests, however, the value decreases rapidly, being governed by the rate of dip and the distance from the crests. The greater the dip the greater is the corresponding decrease in value with increasing distance, and in the troughs of the neighboring synclines the lands theoretically have no oil and gas value.

On applying the principles above given to the dome, it would appear that the most valuable land on this structure is included in the NW. $\frac{1}{4}$ sec. 22, the E. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 21, the southeastern part of the SE. $\frac{1}{4}$ sec. 16, and the SW. $\frac{1}{4}$ and W. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 15. The rest of sec. 15, the northwest half of sec. 22, the northeast half of sec. 21,

the southeast half of sec. 16, the SE. $\frac{1}{4}$ sec. 10, the southwestern part of sec. 11, and a small area in the western and northwestern parts of sec. 14 are to be considered as next in value. Outside of these areas the probable value of the land decreases rapidly as its distance from the central area increases. As the dip is greater on the southeast side of the dome, the value of the land in this direction decreases more rapidly than it does on the west and northwest flanks.

The valuation of the land on the anticline is much more difficult than of that on the dome, because the rock outcrops on which the determination of structure depends are much fewer in number. If the dip of the rocks on the anticline corresponds to the dip of the rocks on the dome, the steeper dips should be found on the southeast side, a relation which places the crest nearer the eastern than the western margin of the anticline. The crest appears to be twice as far from the belt of rocks outlining the western margin of the fold (see p. 127) as from the similar belt on the east and probably crosses secs. 30 and 31, T. 24 N., R. 1 W., as indicated by dips in a few rock outcrops in that vicinity. The highest land values would probably be included in a strip about a mile wide extending from sec. 1, T. 23 N., R. 2 W., northeastward to sec. 16, T. 24 N., R. 1 W. This strip would include parts or all of sec. 1, T. 23 N., R. 2 W.; sec. 6, T. 23 N., R. 1 W.; sec. 36, T. 24 N., R. 2 W., and secs. 31, 32, 30, 29, 19, 20, 21, 17, and 16, T. 24 N., R. 1 W. Land adjacent to this strip is promising territory, although not of equal value with the strip. Because of the greater dip on the southeast side of the anticline, land values decrease more rapidly in that direction than on the northwest side. To the northeast, where practically nothing can be determined as to the structure of the rocks, the values may also decrease.

CONCLUSIONS REGARDING THE POSSIBILITIES OF THE FIRST THREE TEST WELLS.

In view of the fact that the original test well in this region is being drilled on the dome, interest naturally centers on this local structure. Though the well is not on the highest point of the dome, which is in the south-central part of sec. 15, yet it is believed that if it is drilled deep enough it will make a fair test of the dome.

The anticline, because of its larger areal extent and possible greater dip to the east, may be more promising than the dome. The two wells being drilled by the Humphreys Petroleum Co. appear to be located on a favorable part of the anticline. Whether they are on the highest part of the anticline can not be determined because of the doubt as to the location and configuration of the anticlinal crest. At the time this report was written these wells were not deep enough to base any definite conclusions on their findings.

WELL RECORDS.

The following detailed records of wells were obtained in the course of the investigation:

Log of Mid-Co. Petroleum Co.'s No. 1 well in the N. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 22, T. 23 N., R. 2 W., near Billings, Okla.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	<i>Fect.</i>	<i>Fect.</i>		<i>Fect.</i>	<i>Fect.</i>
Earth.....	6	6	Hard sand.....	15	640
Lime.....	24	30	Red rock.....	56	696
Sand.....	4	34	Hard slate.....	19	715
Slate.....	16	50	Red rock.....	25	740
Red rock.....	10	60	Gas sand.....	15	755
Blue slate.....	37	97	Slate.....	10	765
White shale.....	13	110	Soft gray lime.....	42	807
Red rock.....	5	115	Red rock.....	23	830
Slate.....	20	135	Gas sand.....	12	842
Red rock.....	105	240	Red rock.....	18	860
White slate.....	10	250	Hard sand and gas.....	10	870
Red rock.....	15	265	Red rock.....	14	884
Lime.....	4	269	Hard, gritty lime, gas.....	21	905
Red rock.....	46	315	Hard slate.....	10	915
Slate.....	10	325	Red rock.....	112	1,027
Red rock.....	5	330	Gas sand.....	20	1,047
White slate.....	8	338	Blue slate.....	2	1,049
Red rock.....	17	355	Sand and lime.....	17	1,066
Soft slate.....	10	365	Red rock.....	64	1,130
Soft red rock.....	15	380	Lime.....	6	1,136
Lime.....	8	388	Red rock.....	14	1,150
Sand rock.....	7	395	First water sand; water salty.....	20	1,170
White slate.....	25	420	Slate.....	25	1,195
Hard lime.....	15	435	Lime.....	23	1,218
Soft lime.....	15	450	Red rock.....	52	1,270
White slate.....	42	492	Lime.....	30	1,300
Red rock.....	28	520	Brown slate.....	15	1,315
Gray lime.....	15	535	Lime.....	75	1,390
Red rock.....	25	560	Blue slate.....	5	1,395
Hard slate.....	10	570	Lime.....	5	1,400
Gas sand.....	12	582	Lime and slate.....	76	1,476
Red rock.....	38	620	Gas sand.....	69	1,545
Blue lime.....	5	625	Slate.....	25	1,570

Log of the Watchorn & Fortuna Oil Co.'s 101 Ranch well No. 1, in the SW. $\frac{1}{4}$ sec. 33, T. 23 N., R. 3 E.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	<i>Feet.</i>	<i>Feet.</i>		<i>Feet.</i>	<i>Feet.</i>
Red bed.....	40	40	Lime.....	5	1,140
Sandstone.....	5	45	Blue shale.....	50	1,190
Red bed.....	5	50	Lime.....	5	1,195
Sandstone.....	20	70	Blue shale.....	90	1,285
Red bed.....	190	260	Gray sandy shale.....	30	1,315
Lime.....	2	262	Lime.....	4	1,319
Red bed.....	28	290	Sand.....	16	1,335
Water sand.....	5	295	Blue shale.....	65	1,400
Lime.....	10	305	Sand.....	25	1,425
Red bed.....	10	315	Sandy shale.....	25	1,450
Water sand (hole filled with water).....	35	350	Blue shale (streak water sand 1,555).....	120	1,570
Lime.....	18	368	Hard sand.....	5	1,575
Red mud.....	5	373	Blue shale.....	105	1,680
Red bed.....	62	435	Red bed.....	10	1,690
Water sand.....	10	445	Water sand.....	15	1,705
Red bed.....	10	455	Sand (shelly).....	15	1,720
Blue slate.....	20	475	Hard sand.....	5	1,725
Red bed.....	25	500	Blue shale.....	5	1,730
Lime.....	6	506	Broken sand.....	25	1,765
Blue shale.....	14	520	Blue shale.....	35	1,800
Lime.....	10	530	Blue slate.....	10	1,810
Blue shale.....	70	600	Hard lime.....	5	1,815
Red bed.....	10	610	Sandy lime.....	15	1,830
Water sand.....	10	620	Broken lime, sandy.....	30	1,860
Blue slate.....	10	630	Hard lime.....	5	1,865
Blue shale.....	195	825	Broken lime.....	10	1,875
Red bed.....	15	840	Broken lime, shelly.....	20	1,895
Blue shale.....	25	865	Broken lime.....	20	1,915
Lime.....	5	870	Blue shale.....	20	1,935
Blue shale.....	70	940	Sand.....	25	1,960
Water sand.....	10	950	Blue shale.....	30	1,990
Red bed.....	35	985	Sand; gas enough to blow water out of hole.....	5	1,995
Blue shale.....	65	1,040	Sand.....	5	2,000
Water sand.....	10	1,050	Broken sand.....	12	2,012
Blue shale.....	5	1,055	Shell.....	3	2,015
Water sand.....	20	1,075	Sand shelly, big gas.....	5	2,020
Blue shale.....	30	1,105	Sand shelly, gas increasing....	20	2,040
Lime.....	4	1,109			
Blue shale.....	26	1,135			

Casing record: 15 $\frac{1}{2}$ -inch, 373 feet; 12 $\frac{1}{2}$ -inch, 850 feet; 10-inch, 1,561 feet; 8 $\frac{1}{2}$ -inch, 2,016 feet; 6 $\frac{1}{2}$ -inch, 2,041 feet.

Log of 101 Ranch Oil Co.'s Flossie Running After Arrow well No. 16, in the W. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 17, T. 25 N., R. 2 E.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	<i>Feet.</i>	<i>Feet.</i>		<i>Feet.</i>	<i>Feet.</i>
Unrecorded.....	34	34	Sandy shale.....	13	925
Red rock.....	56	90	Blue slate.....	45	970
Lime.....	10	100	Sand (oil and gas).....	24	994
Red rock.....	120	220	Shale, gray.....	41	1,035
Shale, brown.....	13	233	Lime shells.....	15	1,050
Lime, sandy.....	14	247	Shale, gray.....	50	1,100
Red rock.....	53	300	Lime shells.....	50	1,150
Lime.....	10	310	Sandy shale.....	86	1,236
Red rock.....	26	336	Lime.....	14	1,250
Lime.....	31	367	Blue shale.....	30	1,280
Red rock.....	63	430	Lime.....	7	1,287
Lime.....	14	444	Red rock.....	13	1,300
Red rock.....	34	478	Blue shale.....	20	1,320
Lime.....	4	482	Lime.....	20	1,340
Red rock.....	63	545	Sandy shale.....	10	1,350
Sand (gas).....	30	575	Sand (oil).....	13	1,363
Red rock.....	25	600	Sand (water).....	22	1,385
Lime.....	73	673	Shale, blue.....	10	1,395
Sand (gas).....	10	683	Lime.....	14	1,409
Shale, sandy.....	22	705	Sandy shale.....	36	1,445
Red rock.....	10	715	Lime.....	30	1,475
Lime.....	50	765	Brown shale.....	33	1,508
Slate, blue.....	15	780	Lime.....	22	1,530
Lime shells.....	72	852	Brown shale.....	17	1,547
Lime.....	10	862	Red rock.....	17	1,554
Gray shale.....	43	905	Sand (gas).....	14	1,568
Lime.....	7	912			

Casing record: 8 $\frac{1}{2}$ -inch, 1,035 feet; 6 $\frac{1}{2}$ -inch, 1,320 feet; 4 $\frac{1}{2}$ -inch, 1,445 feet; packer, 1,520 feet.

Log of Margaret Primeaux No. 7 well in sec. 4, T. 25 N., R. 2 E.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	Feet.	Feet.		Feet.	Feet.
Soll.....	2	2	Sand.....	5	1,685
Slate.....	48	50	Slate.....	15	1,700
Sand and gravel.....	8	58	Sand (hard; bad cave).....	35	1,735
Lime.....	6	64	Slate.....	12	1,748
Slate.....	10	74	Lime.....	10	1,758
Red rock.....	98	170	Red rock.....	5	1,763
Lime.....	5	175	Lime.....	70	1,770
Slate.....	10	185	Black shale (very cavy).....	44	1,814
Lime.....	50	235	Lime.....	13	1,827
Red rock.....	65	300	Slate.....	13	1,840
Lime.....	2	302	Lime.....	7	1,847
Shale.....	4	306	Slate.....	43	1,890
Lime.....	3	309	Lime.....	5	1,895
Shale.....	13	322	Slate.....	3	1,898
Lime.....	11	333	Lime.....	4	1,912
Slate.....	4	337	Slate.....	91	2,003
Lime.....	13	350	Sand (hole full of water).....	32	2,035
Red rock.....	90	440	Slate.....	3	2,038
Sand (13,000,000 feet of gas).....	12	452	Lime.....	7	2,045
Slate.....	138	590	Slate.....	15	2,060
Lime.....	4	594	Lime.....	12	2,072
Slate.....	13	607	Slate.....	32	2,104
Lime.....	11	618	Lime.....	10	2,114
Slate.....	5	623	Slate.....	14	2,128
Lime.....	42	665	Lime.....	10	2,138
Slate.....	25	690	Slate.....	11	2,149
Lime.....	40	730	Lime (3 feet below water).....	1	2,150
Slate.....	40	770	Sand (3,000,000 feet of gas at 2,150 feet).....	75	2,225
Lime.....	5	775	Lime and sand.....	120	2,355
Slate.....	15	790	Sand.....	10	2,365
Lime.....	10	800	Black slate.....	47	2,412
Slate.....	40	840	Sand.....	3	2,415
Lime.....	5	845	Slate.....	125	2,540
Slate.....	75	920	Lime.....	8	2,548
Lime.....	10	930	Brown shale.....	82	2,630
Slate.....	25	955	Lime.....	4	2,634
Sand.....	15	970	Brown shale.....	31	2,665
Slate.....	70	1,040	Lime.....	8	2,673
Lime.....	5	1,045	Brown sand.....	15	2,688
Slate.....	60	1,105	Light sand.....	12	2,700
Lime.....	3	1,108	Slate.....	16	2,716
Slate.....	17	1,125	Sand.....	24	2,740
Lime.....	5	1,130	Coarse sand.....	15	2,755
Slate.....	35	1,165	Light sand.....	15	2,770
Lime.....	13	1,178	White sand (3 ballers water).....	10	2,780
Slate.....	22	1,200	Blue lime (very hard).....	25	2,805
Sand.....	20	1,220	Black slate.....	90	2,895
Slate.....	15	1,235	Sandy shale.....	35	2,930
Lime.....	10	1,245	Black slate.....	65	2,995
Slate.....	25	1,270	Lime.....	7	3,002
Lime.....	20	1,290	Brown shale.....	4	3,006
Slate.....	35	1,325	Lime.....	14	3,020
Lime.....	10	1,335	Blue shale.....	22	3,042
Slate.....	10	1,345	Bluish sand.....	23	3,065
Sand (hole full of water).....	30	1,375	Blue slate.....	20	3,065
Slate.....	25	1,400	Gray sand.....	13	3,098
Lime.....	5	1,405	Gray slate.....	27	3,125
Slate.....	13	1,418	Blue shale.....	43	3,168
Lime.....	3	1,421	Lime.....	19	3,187
Slate.....	14	1,435	Blue shale.....	13	3,200
Lime and sand (water).....	13	1,448	Lime (very hard).....	2	3,202
Lime.....	4	1,452	Shale.....	9	3,211
Slate.....	18	1,460	Lime.....	16	3,227
Lime.....	6	1,466	Sand and lime.....	15	3,242
Slate.....	24	1,490	Shale.....	6	3,248
Lime.....	20	1,510	Lime.....	62	3,310
Slate.....	10	1,520	Black shale.....	5	3,315
Lime.....	3	1,523	Lime.....	10	3,325
Slate.....	9	1,532	Black shale.....	2	3,327
Lime.....	4	1,536	Lime.....	13	3,340
Slate.....	3	1,539	Black shale.....	7	3,347
Red rock.....	2	1,541	Lime.....	7	3,354
Slate.....	1	1,542	Black shale.....	18	3,372
Sand (showing of oil).....	10	1,552	Lime.....	8	3,380
Slate.....	25	1,577	Black shale.....	10	3,390
Red rock.....	3	1,580	Lime.....	7	3,397
Lime.....	5	1,585	Black shale.....	30	3,427
Slate.....	10	1,595	Lime.....	3	3,430
Lime.....	15	1,610	Black shale.....	5	3,435
Slate.....	35	1,645	Sandy lime (water).....	10	3,445
Lime.....	10	1,655	Shale.....	10	3,455
Sand.....	10	1,665	Sandy lime.....	2	3,457
Slate.....	15	1,680			

Log of Margaret Primeaux No. 7 well in sec. 4, T. 25 N., R. 2 E.—Continued.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	<i>Fect.</i>	<i>Fect.</i>		<i>Fect.</i>	<i>Fect.</i>
Black shale.....	11	3,468	Hard lime.....	5	3,570
Red rock.....	2	3,470	Sand, hard.....	5	3,575
Lime.....	2	3,472	Blue shale.....	5	3,580
Sand, gray, very hard.....	10	3,482	Lime shells and shale.....	11	3,591
Blue shale.....	14	3,496	Lime.....	7	3,598
Sand, like oil sand.....	14	3,510	Blue shale.....	27	3,625
Blue shale.....	15	3,525	Sand, little oil.....	8	3,633
Lime.....	3	3,528	Hard sand.....	15	3,648
Shale.....	7	3,535	Lime.....	4	3,652
Red rock.....	5	3,540	Sand, very hard, showing of oil.....	73	3,725
Blue shale.....	15	3,555	Lime, very hard.....	29	3,754
Lime.....	5	3,560			
Black shale.....	5	3,565			

Casing record: 12½-inch, 73 feet; 10-inch, 610 feet; 8½-inch, 1,260 feet; 6½-inch, 2,038 feet; 5½-inch, 2,632 feet.

Log of 101 Ranch Oil Co.'s 101 Ranch well No. 1, in the NE. ¼ sec. 25, T. 25 N., R. 1 E.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	<i>Fect.</i>	<i>Fect.</i>		<i>Fect.</i>	<i>Fect.</i>
Sandy soil.....	19	19	Black slate.....	10	1,460
Gravel.....	40	59	Very hard sand.....	56	1,516
White clay (water).....	10	69	Black shale.....	1	1,522
Red rock.....	12	81	Fine hard sand.....	7	1,529
Gritty slate.....	8	89	Soft shale.....	20	1,549
Red rock.....	21	110	White sand (water).....	28	1,577
White shale or clay.....	42	152	Blue shale.....	3	1,580
Lime shell.....	9	161	Gritty lime.....	5	1,585
White shale or clay.....	44	205	Black slate.....	53	1,638
Red rock.....	26	231	Sandy lime.....	25	1,663
Lime shell.....	3	234	Soft black shale.....	22	1,685
Red rock.....	60	294	Red shale.....	5	1,690
Brownish lime.....	4	298	White sand.....	15	1,705
Hard black slate.....	28	326	Black slate.....	3	1,708
Reddish lime.....	24	350	White sand.....	28	1,736
Red rock.....	35	385	Black shale.....	20	1,756
Gritty slate.....	20	405	Lime shell.....	7	1,763
Red rock.....	22	427	Soft black shale.....	36	1,799
White shale.....	8	435	White sand (water).....	39	1,838
Brownish lime.....	8	443	Soft shale.....	4	1,842
Hard grayish lime.....	22	465	Gritty gray lime.....	10	1,852
Red shale.....	35	500	Black shale.....	6	1,858
Lime shell.....	12	512	Slate and shell.....	22	1,880
Red rock.....	54	570	Soft black shale.....	5	1,885
Red sand.....	23	593	Red shale.....	7	1,892
Hard white lime.....	5	598	White lime.....	30	1,922
Red shale.....	27	625	Soft black shale.....	13	1,933
White sand.....	35	660	Soft red shale.....	15	1,950
Red shale.....	42	702	White lime.....	28	1,978
White sand.....	34	736	Red rock (cavy).....	22	2,000
Black slate.....	6	742	Hard gray lime.....	15	2,015
Hard lime.....	38	780	Lime shell.....	3	2,018
White slate.....	50	830	Sandy lime.....	19	2,037
Grayish lime.....	24	854	Brown shale.....	3	2,040
Black slate with shells.....	18	872	White sand.....	5	2,045
Black slate with hard shells.....	24	896	White shale.....	13	2,058
Black slate.....	6	902	White sand.....	30	2,088
Slate and shells.....	21	923	Black shale.....	20	2,108
Reddish tinted slate.....	37	960	Hard lime.....	6	2,114
Gritty shell in black slate.....	45	1,005	Black slate.....	49	2,163
White and black sand.....	12	1,017	Hard shell.....	3	2,166
Black slate.....	45	1,062	Black slate.....	14	2,180
Slate and shell.....	4	1,066	Hard white sand.....	10	2,190
Soft slate.....	85	1,151	Red brown shale.....	4	2,194
Lime.....	4	1,155	White slate.....	5	2,199
Very soft slate.....	75	1,230	Very hard white lime (water).....	43	2,242
Hard white sand.....	6	1,236	Black slate.....	26	2,268
Soft black slate.....	24	1,260	Dark lime.....	11	2,279
Dark soft shale.....	12	1,272	Black shale.....	3	2,282
Lime cavings.....	43	1,315	White sand (salt water).....	18	2,300
White sand (water).....	19	1,334	Dark shale.....	3	2,303
Slate and shells.....	33	1,367	Very white sand.....	59	2,362
Hard lime.....	18	1,385	Shale, black.....	43	2,405
Soft dark lime.....	10	1,395	Dark lime.....	6	2,411
Soft black shale.....	23	1,418	Blue shale.....	54	2,465
Red rock.....	15	1,433	White shale.....	20	2,485
White sand.....	17	1,450	Dark blue shale.....	35	2,520
			White sand.....	56	2,576

Log of H. F. Wolf well No. 1, SW. $\frac{1}{4}$ sec. 6, T. 28 N., R. 1 E.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	<i>Feet.</i>	<i>Feet.</i>		<i>Feet.</i>	<i>Feet.</i>
Soil.....	5	5	Shale.....	25	1,255
Clay.....	55	60	Lime.....	70	1,325
Lime.....	17	77	Shale.....	15	1,340
Clay.....	2	79	Lime and shale.....	70	1,410
Lime.....	17	96	Lime.....	45	1,455
Slate.....	14	110	Sand.....	30	1,485
Lime.....	15	125	Shale.....	40	1,525
Slate.....	5	130	Lime.....	175	1,700
Lime.....	5	135	Red rock.....	5	1,705
Slate.....	20	155	Lime.....	20	1,725
Lime.....	8	163	Shale.....	85	1,810
Slate.....	7	170	Sand (water).....	55	1,865
Lime.....	45	215	Shale.....	5	1,870
Slate.....	10	225	Lime.....	45	1,915
Lime (gas).....	20	245	Shale.....	15	1,930
Red rock.....	25	270	Sand.....	15	1,945
Slate.....	25	295	Red rock.....	7	1,952
Lime.....	10	305	Shale.....	5	1,957
Slate.....	10	315	Sandy lime.....	13	1,970
Lime.....	5	320	Red rock.....	5	1,975
Slate.....	25	345	Blue slate.....	5	1,980
Sand (gas).....	40	385	Sand (oil showing).....	8	1,988
Lime.....	10	395	Blue shale.....	6	1,994
Slate.....	5	400	Lime.....	36	2,030
Red rock.....	20	420	Blue slate (cavy).....	50	2,080
Slate.....	20	440	Shale.....	125	2,205
Lime.....	5	445	Sandy lime.....	15	2,220
Shale.....	15	460	Shale.....	35	2,255
Sand (gas).....	25	485	Sand (6,000,000 feet of gas) ..	15	2,270
Lime.....	10	495	Shale.....	20	2,290
Slate.....	10	505	Sand (water).....	50	2,340
Red rock.....	10	515	Slate.....	265	2,605
Lime.....	10	525	Sandy slate (hard).....	5	2,610
Brown shale.....	15	540	Sand (gas).....	10	2,630
Red rock.....	5	545	Sand, brown (gas).....	20	2,650
Lime (gas at 555 feet).....	25	570	Sand (showing oil).....	7	2,657
Red rock.....	15	585	Lime sand (water).....	8	2,665
Brown shale.....	5	590	Sand.....	65	2,730
Lime.....	10	600	Shale.....	30	2,760
Blue shale.....	30	630	Sand.....	25	2,785
Red rock.....	10	640	Shale.....	135	2,920
Lime sand (gas).....	5	645	Lime.....	10	2,930
Red rock (cavy).....	15	660	Green slate.....	20	2,950
Sand (gas at 670 feet).....	20	680	Sand (500,000 feet of gas) ..	50	3,000
Shale.....	17	697	Slate.....	20	3,020
Lime.....	23	720	Lime.....	10	3,030
Shale.....	5	725	Slate.....	5	3,035
Lime.....	90	815	Lime.....	20	3,055
Lime (gas).....	45	860	Black slate.....	5	3,060
Shale.....	5	865	Lime.....	35	3,095
Lime.....	17	882	Black slate.....	10	3,105
Shale.....	33	915	Lime.....	65	3,170
Lime (gas).....	50	965	Black slate.....	5	3,175
Shale.....	215	1,180	Shale.....	65	3,240
Lime (gas).....	40	1,220	Sandy shale (very hard).....	10	3,250
Lime.....	10	1,230	Sand (30,000,000 feet of gas) ..	20	3,270

Casing record: 15 $\frac{1}{2}$ -inch, 135 feet; 12 $\frac{1}{2}$ -inch, 680 feet; 10-inch, 1,040 feet; 8 $\frac{1}{2}$ -inch, 2,080 feet; 6 $\frac{1}{2}$ -inch, 2,360 feet; 5 $\frac{1}{2}$ -inch, 2,734 feet.

Log of Gus Swenson well No. 1, NE. $\frac{1}{4}$ sec. 32, T. 29 N., R. 1 E.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	<i>Feet.</i>	<i>Feet.</i>		<i>Feet.</i>	<i>Feet.</i>
Soil.....	5	5	Lime.....	20	1,220
Clay (water).....	9	14	Slate.....	60	1,280
Shale.....	12	26	Lime.....	10	1,300
Gypsum.....	4	30	Slate.....	120	1,420
Shale.....	16	46	Lime.....	24	1,444
Gypsum.....	8	54	Sand (water, little gas).....	36	1,480
Shale.....	25	79	Lime.....	20	1,500
Lime.....	8	82	Shale.....	110	1,610
Shale.....	19	101	Lime.....	20	1,630
Lime.....	4	105	Shale.....	10	1,640
Red rock.....	18	123	Lime.....	3	1,643
Shale.....	140	263	Shale.....	97	1,740
Red rock.....	34	297	Lime.....	10	1,750
Shale.....	30	327	Sand (gas).....	25	1,775
Lime.....	5	332	Red rock.....	15	1,790
Shale.....	14	346	Shale.....	10	1,800
Lime.....	4	350	Sand (water).....	25	1,825
Sand (gas).....	20	370	Shale.....	15	1,840
Shale.....	65	435	Red rock.....	60	1,900
Lime, sand (water).....	7	442	Lime.....	40	1,940
Red rock.....	15	457	Shale.....	20	1,960
Shale.....	41	498	Sand (oil, good showing).....	25	1,985
Lime.....	3	501	Sand (water).....	2	1,987
Slate.....	26	527	Slate.....	13	2,000
Lime.....	10	537	Lime.....	7	2,007
Shale.....	20	557	Slate.....	88	2,090
Sand (gas, into water).....	33	590	Lime.....	10	2,100
Shale.....	22	612	Red rock.....	10	2,110
Lime.....	7	619	Lime.....	105	2,215
Slate.....	21	640	Slate.....	63	2,278
Red rock (caved badly).....	21	661	Sand (oil, good showing).....	15	2,293
Shale.....	6	667	Slate.....	5	2,298
Slate.....	2	669	Sand (water).....	12	2,310
Lime.....	5	674	Slate.....	345	2,655
Shale.....	41	715	Sand (oil).....	32	2,687
Sand.....	37	742	Sand.....	73	2,750
Shale.....	28	770	Slate.....	5	2,755
Sand (water).....	26	796	Lime.....	10	2,765
Shale.....	80	876	Sand (water).....	15	2,780
Lime.....	9	885	Lime.....	220	3,000
Red rock.....	17	902	Shale.....	50	3,050
Shale.....	18	920	Sand (oil, fair showing).....	20	3,070
Sand (gas).....	22	942	Lime.....	130	3,200
Lime.....	3	945	Shale, slate.....	100	3,300
Sand (water).....	55	1,000	Sand (water).....	30	3,330
Red rock.....	30	1,030	Slate.....	25	3,355
Shale.....	70	1,100	Sand (gas).....	10	3,365
Lime.....	15	1,115	Oil sand (still in sand).....	20	3,385
Shale.....	95	1,210			

Casing record: 10-inch, 696 feet; 8 $\frac{1}{2}$ -inch, — feet; 6 $\frac{1}{2}$ -inch, 2,408 feet; 5 $\frac{1}{4}$ -inch, 2,900 feet, and underreamed to 3,337 feet.

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 641—F

**OIL SHALE IN NORTHWESTERN COLORADO
AND ADJACENT AREAS**

BY

DEAN E. WINCHESTER

Contributions to economic geology, 1916, Part II

(Pages 139-198)

Published December 18, 1916



WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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OIL SHALE IN NORTHWESTERN COLORADO AND ADJACENT AREAS.

By DEAN E. WINCHESTER.

PREFATORY NOTE.

By MARIUS R. CAMPBELL.

For several years it has been known that some of the shale of the Green River formation in northwestern Colorado and northeastern Utah would produce oil when subjected to destructive distillation, but the yield of petroleum from the oil fields was so great that production by distillation did not seem to be feasible, despite the fact that in Scotland such an industry has long been developed and is to-day paying dividends on a large investment.

The United States Geological Survey has regarded this oil shale as a great reserve—an undeveloped resource—and one that would be developed as soon as the demand for petroleum greatly exceeded the supply. In anticipation of such an event, E. G. Woodruff and David T. Day began, in 1913, an examination of the Green River formation in Colorado and Utah and made rough field tests to determine the richness of the shale. Although these tests were not entirely satisfactory, they tended to confirm the general impression that this shale constitutes a source of oil which, sooner or later, will be called into use. Of course, no prediction could be made as to the date when this additional supply would be needed, but the Survey felt justified in continuing the geologic investigation, in order that when the time of need arrived it would have first-hand information on the richness and quantity of the shale available for distillation. Accordingly the field examination was continued during the summers of 1914 and 1915 by Dean E. Winchester, who devised a more efficient and portable apparatus for determining not only the quantity of crude oil in the shale but also the amount of gas and of ammonium sulphate (fertilizer) that might be obtained as a by-product and sold. The experiments of Mr. Winchester confirmed the results of the work done in the previous year and indicated even more strongly that a great quantity of high-class fuel is locked up in this shale.

At the present time, owing to the great increase in the consumption of gasoline and the failure to discover large new oil fields, it

seems that the day is approaching when this additional supply will be needed and that the public will demand all the information in the possession of the Geological Survey on this subject. I feel confident that this report of Mr. Winchester will supply many of the data needed to establish and develop the oil-shale industry in this country. The report contains information showing the quantity and quality of the oil that may be distilled from the richer beds of shale, the number of such beds at the different localities examined, and the general distribution of the shale throughout northwestern Colorado and adjacent parts of Utah and Wyoming. Mr. Winchester's results, which have been corroborated by tests made in the laboratory of the Bureau of Mines, show that the quantity of oil that can be derived from such shale ranges from less than 1 gallon to 90 gallons to the ton of shale. The field tests, however, were not intended to determine the best method of utilizing the shale in commercial operations, but simply to provide data for fixing approximately the value of the shale as it is found to-day. Mr. Winchester, as a result of the field tests, estimates that in Colorado alone there is enough shale to produce 20,000,000,000 barrels of oil, and it seems probable that in actual practice a greater yield than this can be obtained. He also estimates that 300,000,000 tons of ammonium sulphate could be recovered as a by-product in the manufacture of the oil.

The results given in this paper show that although the Geological Survey has done only reconnaissance work in this region, it has demonstrated that the shale of the Green River formation will yield a vast quantity of oil, gas sufficient to carry on the process of distillation, and fertilizer enough to enrich most of the farms of the Middle West, and that this reserve is ready whenever the demand is sufficient to warrant the establishment of a new industry to supplement the failing supply of petroleum from the oil fields.

INTRODUCTION.

The economic study of the oil shale of Colorado and Utah was begun in 1913 by Woodruff and Day,¹ and the results of their preliminary work showed that the shale of the Green River formation in Colorado and Utah will yield oil in commercial quantities when subjected to destructive distillation. As a result of a more detailed examination along the north, east, and southeast sides of the Uinta Basin, in northwestern Colorado, made during the summer of 1914 and in eastern Utah in 1915 the writer finds that although the thickest and richest beds of shale are exposed along the southern margin of the basin, nearly every section examined contains beds of shale more than 3 feet thick that will yield considerable oil. An examination of

¹ Woodruff, E. G., and Day, D. T., Oil shale of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 581, pp. 1-21, 1914 (Bull. 581-A).

the same formation in southwestern Wyoming in 1915 indicates that in that area there are no thick beds of rich shale.

The oil shale of the United States has received very little attention, chiefly because petroleum has been abundant. Before petroleum was discovered in Pennsylvania the Mormons distilled oil from shale near Juab, Utah, where the ruins of an old still can yet be seen. Many attempts have been made to distill cannel coal, and a few experiments have been made with the Devonian black shale of the East, but no shale-oil industry has been established in America. According to Baskerville¹ there were 55 oil companies in the United States in 1860. "Many of the companies were of small capacity and most of them were not more than fairly started when the discovery of petroleum paralyzed the industry." In Scotland, however, several well-established plants mine and distill shale of Carboniferous age. In 1908, according to Ells,² the oil-shale industry of Scotland employed about 8,300 men, of whom nearly 4,000 were miners; and in the preceding year the production of oil shale in Scotland amounted to 2,775,799 (long) tons, and the average yield of crude oil was 23 (Imperial) gallons to the long ton (24.6 United States gallons to the short ton).³ The operations have paid dividends in spite of this low yield, because of the cheapness of labor, the value of the by-products, and lack of competition with petroleum. The cost of mining shale in Scotland is reported by the same author to be \$1 a ton, the cost of distilling the crude oil from the shale is 40 cents a ton, and the cost of making ammonium sulphate (the principal by-product) from the shale is 46 cents a ton. All mining in Scotland is underground, and in many of the mines the shale beds dip at angles of 30° to 60° and there are numerous faults, which greatly increase the expense of mining. At many places in Colorado and Utah, however, the rich shale has only a light overburden (see Pl. XI) and could be mined with a steam shovel.

In Colorado alone there is sufficient shale, in beds that are 3 feet or more thick and capable of yielding more oil than the average shale now mined in Scotland, to yield about 20,000,000,000 barrels of crude oil, from which 2,000,000,000 barrels of gasoline may be extracted by ordinary methods of refining, and in Utah there is probably an equal amount of shale just as rich. The same shale in Colorado, in addition to the oil, should produce with but little added cost about 300,000,000

¹ Baskerville, Charles, Economic possibilities of American oil shales: Eng. and Min. Jour., vol. 88, pp. 149-154, 195-199, 1909.

² Ells, R. W., Report on tests made in Scotland of oil shale sent from New Brunswick in the spring of 1908, with a view of ascertaining its economic value, especially as regards the yield of crude oil and sulphate of ammonia, pp. 24, 26, Canada Dept. Mines, 1910.

³ In this paper results of distillation are given in United States gallons (42 gallons to the barrel) and referred to the short ton (2,000 pounds). Care should be taken in comparing figures with those given in reports on oil shale of Scotland, in which results are given in Imperial gallons (35 gallons to the barrel) and referred to the long ton (2,240 pounds).

tons of ammonium sulphate, a compound especially valuable as a fertilizer. The industry requires a large equipment of retorts, condensers, and oil refineries, as well as of mining machinery, so that it can not be profitably handled on a small scale.

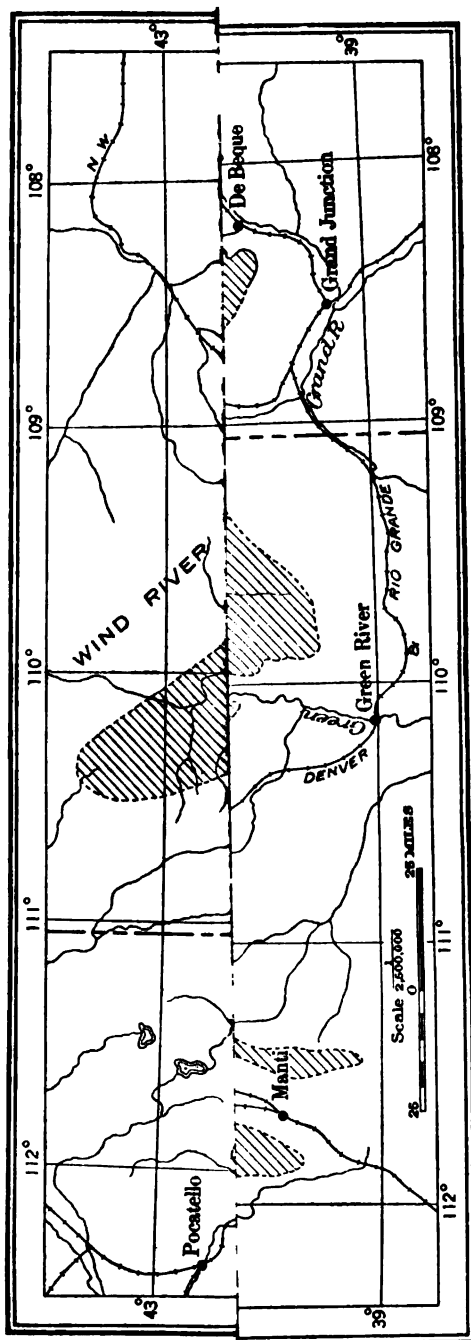
In Scotland, according to Ellis,¹ the following valuable products are manufactured from the shale: (1) permanent gas, used principally for fuel in the retorts; (2) naphtha, gasoline, and motor spirit; (3) burning or lamp oil; (4) intermediate oil used for gas making; (5) lubricating oil; (6) solid paraffin; (7) still grease; (8) still coke, which contains some oil and is used for gas fires, smokeless fuel, and carbon for electrical purposes; (9) sulphate of ammonia [a fertilizer which in the United States is worth from \$50 to \$60 a ton]; and (10) liquid fuel, used in the refineries. The distillation of the oil shale of the Green River formation will probably yield different products, and the processes of distillation used in Scotland may not be well adapted to this shale.

In the 11 field tests made by Woodruff² in 1913, 1 sample of shale yielded as low as 10.4 gallons of oil to the ton of shale; 8 between 16 and 40 gallons, averaging 27.2 gallons; one 45.2 gallons; and one 61.2 gallons. Of the 57 samples tested in 1914 (Nos. 1-57, pp. 152-153), 17 samples yielded less than 10 gallons of oil to the ton of shale; 22 samples between 10 and 20 gallons; 11 samples between 20 and 30 gallons; 3 samples between 30 and 40 gallons; 2 samples 40.6 gallons each; 1 sample 65.3 gallons; and 1 sample 86.8 gallons. Seventy-five samples (Nos. 58-133) were tested in 1915. Of those obtained in Utah (34 samples, Nos. 58-91) 6 yielded less than 10 gallons of oil to the ton of shale; 7 between 10 and 20 gallons; 7 between 20 and 30 gallons; 9 between 30 and 40 gallons; and 5 more than 40 gallons. The maximum yield, 90 gallons to the ton, was obtained from a thin bed near Watson, Utah. Samples 93-132, from Wyoming, yielded less than 30 gallons, except 4, which yielded more than 30 gallons. One of these represented a 2-foot bed, which yielded 50 gallons to the ton.

As these quantities compare favorably with those obtained from the oil shale of Scotland, it seems probable that in time the distillation of oil from the Green River shale may become as important an industry in this country as the distillation of oil from Carboniferous shale has become in Scotland, or if richer raw material can be found here in abundance it may even exceed the present shale-oil industry abroad.

Ellis, R. W., *op. cit.*, pp. 54-56.

²Woodruff, E. G., and Day, D. T., *op. cit.*, p. 4.



KEY MAP OF NORTHWESTERN COLORADO AND ADJACENT AREAS.

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FIELD WORK.

Personnel and methods.—In order to estimate the value of the oil shale of the Green River formation as an economic resource, the writer, assisted by H. M. Robinson and Frank A. Elliott, in 1914, made a careful study of the entire exposed portion of the formation at a number of places along the north, east, and southeast sides of the Uinta Basin in Colorado (localities A to P, Pl. XVIII). During the later part of the season Mr. Robinson made a hasty examination of the shale of the same formation at several places in northeastern Utah (localities 1-4, Pl. X). During the season of 1915 Walter B. Wilson, John N. Massey, and Yong K. Lee assisted the writer in examining the southern part of the area of the Green River formation in southwestern Wyoming and the south side of the Uinta Basin, near the eastern line of Utah. A large number of samples of shale were distilled in the field and in the laboratory of the Bureau of Mines at Washington to determine the quantity of oil and other products which could be obtained from them. Much of the chemical work was done under the direction of David T. Day, of the Bureau of Mines. C. A. Davis, also of the Bureau of Mines, was detailed to the Survey for several months to make a microscopic study of the organic matter in the shale. To Messrs. Day, Davis, and David White, who visited the field early in September, 1914, the writer is indebted for many helpful suggestions concerning methods of work and interpretation of results.

The limits of the Green River formation were mapped in the field and the exact place at which each sample of shale was obtained was determined by the use of telescopic alidade, stadia rod, and plane table. Geologic sections were measured at several localities. The accompanying map of northwestern Colorado and eastern Utah (Pl. XVIII) is compiled from field sheets prepared by the writer, from published and unpublished data collected by Gale¹ in connection with an examination of coal fields in the adjacent areas, and from data shown on the township plats of the General Land Office. The land net was compiled from these plats, but owing to discrepancies between surveys and resurveys it was necessary to make numerous more or less arbitrary adjustments and the land net shown on the map therefore comprises only township lines. The resurvey of the area north of the base line in Colorado and along Douglas Creek south of it was only recently completed, and the corners are well marked, but the corner posts of the much older surveys elsewhere are very poorly preserved or entirely gone. The land survey of that part of eastern Utah shown on Plate XVIII is good. In many places the geologic boundaries shown are taken directly from maps published

¹ Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, 1910.

by Mr. Gale, inasmuch as wherever tested these maps proved to be entirely satisfactory for the purposes of this work. The places from which samples 1-4 were collected are shown on the smaller map (Pl. X).

The map of southwestern Wyoming (Pl. XIX) is compiled from maps by Veatch¹ and Schultz² and unpublished data by Schultz, together with the data collected by the writer during the field work and data shown on the township plats of the General Land Office. A large part of the area has been recently resurveyed, and the land lines are trustworthy, except in the extreme eastern part, where the old survey is known to be very poor.

Area examined.—The examination of 1914 was confined to a narrow strip about the north, east, and southeast sides of the Uinta Basin in Colorado, except that during a short trip into central Utah Mr. Robinson sampled shale beds at the four localities shown on Plate X. A portion of the outcrop of the formation along the Colorado-Utah line near White River was examined, but the greater part of the season was spent along the margin of the main basin to the east. The Green River formation occupies an area of about 1,900 square miles in Colorado and a larger area in northeastern Utah. The main area in Colorado is separated from the Utah part of the Uinta Basin by the Douglas Creek anticline, which extends in a general northerly direction along the valley of Douglas Creek near the State line. The limit of the oil-yielding shale in most places practically coincides with the boundary of the Green River formation, but northwest of Meeker only the lower part of the formation is present, and this is barren of oil. A similar condition prevails south of Grand River.

The eastern edge of the Uinta Basin in Utah, near Watson, was examined in considerable detail during August and September, 1915. Most of the season, however, was spent in a reconnaissance examination of southwestern Wyoming (Pl. XIX). The eastern margin of the Green River formation in Wyoming between the Union Pacific Railroad and the Colorado-Utah-Wyoming line was examined, and samples of shale from the localities indicated on the map were tested. A hurried trip was made across the Green River basin to Fossil, Wyo., and southward along the western part of the area known to contain the Green River formation.

Northwestern Colorado and northeastern Utah.—The surface of the part of the field represented by Plate XVIII consists mainly of deeply dissected uplands surrounded on all sides by more open valleys carved in the shale and soft sandstone of the Wasatch formation,

¹ Veatch, A. C., *Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil*: U. S. Geol. Survey Prof. Paper 56, pl. 3, 1907.

² Schultz, A. R., *The southern part of the Rock Springs coal field, Sweetwater County, Wyo.*: U. S. Geol. Survey Bull. 381, pp. 214-281, 1908.



A. OIL SHALE NORTHEAST OF WATSON, UTAH.

Shows thin bedding in this part of the Green River formation. Darker bands are richest beds. About 600 feet of rock exposed.



B. OIL SHALE ON EAST SIDE OF PICEANCE CREEK NEAR WHITE RIVER, COLO.

Most of the projecting ledges are rich shale.



A. BOOK CLIFFS WEST OF RIFLE, COLO.

Oil shale forms upper cliff. About 3,000 feet of rock exposed. (See fig. 13, p. 145.)



B. GREEN RIVER FORMATION NORTH OF WHITE RIVER, 9 MILES WEST OF RANGELY, COLO.

Dark projecting beds are oil shale. Cliff about 1,000 feet high.

which lies beneath the oil-yielding Green River shale and above the coal-bearing Mesaverde formation. The Book Cliffs near Rifle, Colo. (Pl. XII, *A*), stand about 9,000 feet above sea level. The Grand Hogback, which extends along the eastern margin of the field nearly parallel with the boundary of the Green River formation, reaches an altitude of about 9,500 feet and is formed by the steeply upturned resistant sandstones of the Mesaverde formation. The Green River formation, probably owing to the presence of oil-yielding shale, resists erosion to a marked degree and gives rise along the southern margin of the area to nearly perpendicular and at most places impassable cliffs, which in the vicinity of Rifle and De Beque rise to heights of 3,000 or 4,000 feet above the valley of Grand River, only a few miles distant. (See fig. 13.) West of the Grand Hogback and north of Rio Blanco post office the shale forms hills of considerable prominence, known as the Petrolito Hills. The outcrop of



FIGURE 13.—Section from Grand River near Rullison, Colo., to the Book Cliffs on the north, showing the position of the oil shale.

the oil shale along the east side of the Douglas Creek anticline is marked by nearly perpendicular cliffs known as the Cathedral Bluffs. Cliffs similar to these and equally impassable form the boundary of the formation along White River (Pl. XII, *B*) and southward along the Colorado-Utah State line to a point near Watson, Utah. (See Pl. XI, *A*.)

By far the larger part of this area drains northward to White River through Evacuation, Douglas, Yellow, and Piceance creeks, and to the Pacific Ocean through Green and Colorado rivers. That part of the area south of the Book Cliffs is drained by Grand River, which joins Colorado River in Central Utah. White and Grand rivers and Roan, Douglas, Yellow, and Piceance creeks are the only streams that carry water throughout the year.

The valley of Grand River is traversed by the main line of the Denver & Rio Grande Railroad. The narrow-gage line of the Uintah Railway between Mack, Colo., and Watson, Utah, crosses the Book Cliffs near the Colorado-Utah line and furnishes transportation facilities for a considerable part of the Uinta Basin. The

ranchers and farmers in this area do a very large part of their shipping by way of Meeker, Rifle, and the Denver & Rio Grande Railroad. The proposed extension of the Denver & Salt Lake Railroad ("Moffat road") westward from Craig down Yampa River, to the north of the field, will furnish an additional outlet.

The surface of the area is so rough that wagon travel is forced to follow certain long-used routes, such as the Government road from Rifle to Meeker and the well-kept road between Meeker and Rangely down the valley of White River. Roads also lead from Rangely northwest and southwest to Vernal and Dragon, Utah, respectively, and there is a fair wagon road up Piceance Creek connecting with the Government road at Rio Blanco post office. Aside from these wagon roads there are few routes that can be used to advantage.

The valleys of White and Grand rivers and of Piceance and Roan creeks are occupied by small but prosperous ranches which under irrigation produce alfalfa, timothy, grain, and vegetables. Considerable fruit is raised in the valley of Grand River. The area outside of these valleys is used only for stock range.

Rifle is the largest railroad town in the area and is a shipping point for nearly the entire region. It is the starting point of the mail stage and freight lines which supply Meeker and the settlements in that vicinity. Meeker, a thriving town of 800 inhabitants on White River in T. 1 N., R. 94 W., is the distributing point for a large area to the north, east, and west. Rangely, 60 miles down White River, consists of a store and post office and is connected with Meeker by stage that makes three trips a week. Supplies for Rangely and vicinity are freighted from Dragon, Utah, a station on the Uintah Railway, and Watson, at the end of the same railway 9 miles north of Dragon, is the shipping point for ore from the gilsonite mines of the Uinta Basin and for produce from Ashley Valley, 50 miles to the northwest. A toll road from Watson to Vernal is used by daily automobile mail and passenger stages that connect with the trains of the Uintah Railway. Rio Blanco, halfway between Rifle and Meeker, consists of a small store and post office. Piceance and Sulphur are merely post offices located at ranch houses. De Beque and Grand Valley are small but prosperous towns on the Denver & Rio Grande Railroad south of the Book Cliffs.

Southwestern Wyoming.—That portion of southwestern Wyoming which is shown on the map (Pl. XIX) includes the southern part of the Green River basin and the western rim of the Southern Red Desert Basin. The surface is in most places rolling and covered with vegetation characteristic of arid regions.

Trees grow only along streams and in a few small upland areas. The region is drained through Green River and its tributaries except in the area adjacent to the west line of the State, where the run-off



A. GREEN RIVER FORMATION EAST OF GREEN RIVER CITY, WYO.
Samples of oil shale 127 and 128 taken from beds at base of upper cliff.



B. GREEN RIVER FORMATION IN T. 10 S., R. 15 E., ABOUT 25 MILES NORTH OF SUNNYSIDE, UTAH.



4. SAMPLING BED OF OIL SHALE SOUTH OF GREEN RIVER CITY, WYO.

Shows characteristic weathering of bed containing alternating rich and poor seams. The richer seams are more resistant.



B. SAMPLING BED OF OIL SHALE NEAR WATSON, UTAH.

A, Narrow channel in weathered face, from which sample 65 was taken. B, Larger cut in same bed, from which sample 66 was taken.

finds its way to Great Salt Lake by the way of Bear River. Steep cliffs mark the eastern margin of the main basin, and Green River valley is bordered by precipitous walls for several miles near the town of Green River. (See Pl. XIII, A.) Altitudes range from 5,900 feet above sea level on Green River near Linwood to 8,750 feet in the southwestern part of the area shown on the map.

Green River has its beginning far to the north, in the Wind River Mountains, but its principal tributaries in this area, Blacks Fork and Henrys Fork, rise in the Uinta Mountains of northern Utah. Aside from the three streams mentioned above, together with Hams Fork, a tributary of Blacks Fork, and Bear River, there are in this area very few streams that carry water the year round.

The main line of the Union Pacific Railroad crosses the area in a general westerly direction and is joined at Granger by the Oregon Short Line, which connects with points to the northwest. Rock Springs, Kemmerer, and Evanston, coal-mining towns, and Green River, a railroad division point, are the principal towns of the region. Several villages have been established in the irrigated district around old Fort Bridger and along Henrys Fork near the southern line of the State. Many of the towns on the railroad consist of only a few houses, a store, and a post office. The Lincoln Highway follows in general the line of the Union Pacific Railroad, and good automobile roads connect many of the smaller towns with the railroad and this highway.

TESTS OF THE SHALE.

APPARATUS FOR FIELD DISTILLATION.

A large number of samples of shale were collected (see Pl. XIV) and tested in the field in order that a definite idea of its value as a source of oil might be obtained. Several large samples were also shipped to the chemical laboratory of the Geological Survey so that different methods of treatment might be devised to increase if possible the yield of crude oil and other valuable products. In the early part of the work (1914) the apparatus designed and used by Woodruff and Day¹ during the previous season, described below, was used to make the tests.

The retort into which the shale was charged consisted of a section of 12-inch iron casing pipe 4 feet long, having flanges screwed on the ends and a removable iron plate with asbestos gaskets fitted to each end of the retort. On one side of the retort there was fitted a small steam dome, a pressure gage, and a safety valve. From the top of the dome a pipe led to a block-tin condensing coil in a small water-filled tank. The coil discharged into Wolff bottles set in series and provided with stopcocks so that the liquids could be drawn off without interfering with the operation of the condenser. During the operation the retort was suspended from iron supports in a narrow trench,

¹ Woodruff, E. G., and Day, D. T., op. cit., p. 4.

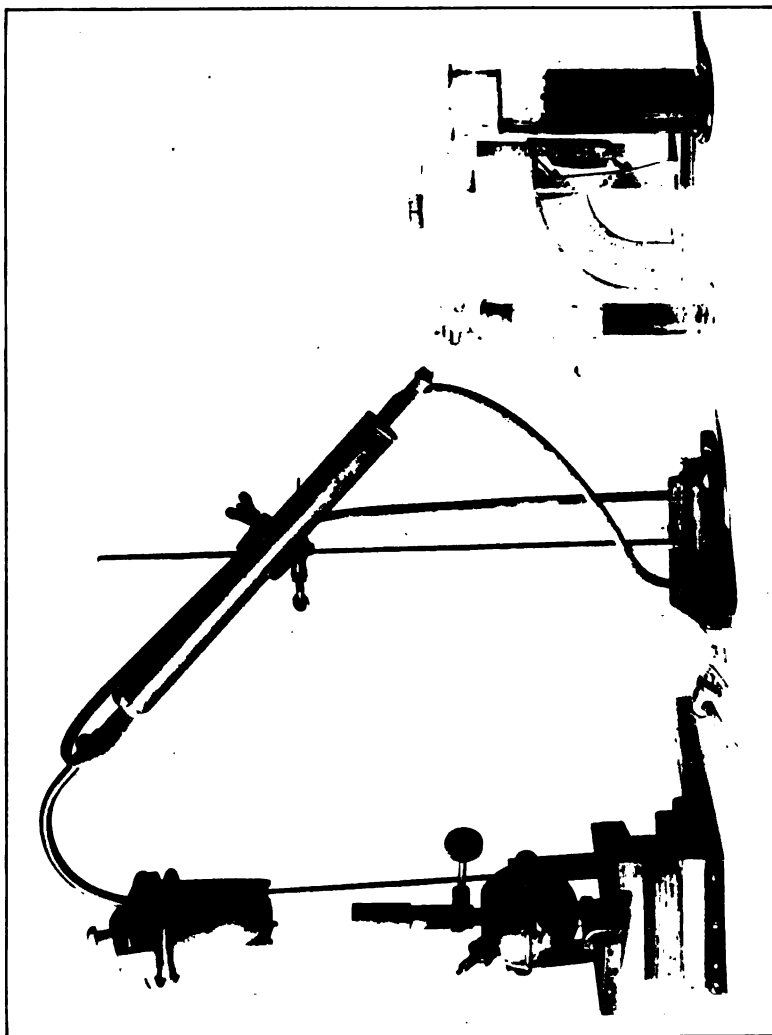
covered with iron plates and earth, and a flue erected at the back. Heat was obtained from a wood fire placed under the retort.

The operation consisted of removing the head, charging the retort with shale broken into pieces not larger than 4 inches in diameter, and replacing the head. Fire was started to give a gentle heat at first and was gradually increased until the lower part of the retort became red hot; then the fire was held constant until near the close of the process, when it was increased for a short time and then allowed to subside. Water vapor, gas, oil and gas, and finally only gas was the order in which the products were obtained. From seven to eight hours' heating was required for a charge.

This apparatus necessitated the mining of a large quantity of shale (100 pounds or more) for each test. The apparatus, being large and not easily transported and eventually becoming unfit for use through leakage, was abandoned and replaced by a small still which required a sample weighing only about 1 pound and which was heated by gasoline torches. With two of these small distilling outfits four samples of shale were tested easily in one working day, whereas only one sample of shale a day could be tested with the larger apparatus. The distilling apparatus used in 1915 (see Pl. XV), which is similar to that used during the later part of the 1914 season, but much more compact and lighter, consists of the following essential parts:

- Two gasoline blast lamps (Barthel's).
- One iron mercury retort (one-half pint) with delivery tubes.
- One brass condenser.
- Two ring stands.
- One 3½-inch ring.
- One large condenser clamp.
- One receiver for condensed liquids (50 cubic centimeter glass graduate).
- One ammonia scrubber (8-ounce bottle filled with glass beads).
- Two pairs combination pliers.
- One postal balance.
- Six feet of rubber tubing.
- Glass tube for connecting condenser, receiver, and ammonia scrubber.
- One glass separatory funnel.

Because of its simplicity and because its flame can be adjusted to any desired angle or length, the Barthel blast lamp was chosen to furnish heat for the still. This lamp consists of a small spherical gasoline tank with burner, mounted on an iron base in such a way that the burner may be turned at any angle. To manipulate the burner the tank is first filled nearly full of gasoline and the cap securely screwed down. Gasoline is placed in the small cuplike depression around the burner and lighted. When this gasoline is burned out, sufficient heat will have been produced to generate gas under pressure, which may be lighted at the end of the burner on opening the burner valve. If the flame is yellow or sputters the burner is not sufficiently hot and must be reheated. The gasoline tank of each burner holds sufficient fuel to keep the blast burning about 2 hours. Inasmuch as each distillation of shale requires from



FIELD APPARATUS FOR DISTILLING OIL SHALE.



4. CHARACTERISTIC WEATHERING OF RICH, MASSIVE OIL SHALE.
Near Welch ranch, T. 1 N., R. 100 W., Colorado.



5. CHARACTERISTIC WEATHERING OF OIL-YIELDING PAPER SHALE,
West side of Piceance Creek near White River, Colo.

3 to 4 hours, two burners are used with each retort. The second torch may be most easily lighted by playing the flame of the first on the burner of the second.

The vessel in which the shale is placed to be heated is an ordinary iron mercury retort (capacity, one-half pint), which is equipped with close-fitting lid and clamp and an iron delivery tube. The delivery tube is fastened to the inner tube of the condenser by a small brass plumber's union, which provides a very easily disconnected joint. The retort is held in place above the flame of the burner by a ring and ring stand.

The condenser used in the outfit consists of an inner tube of thin brass three-eighths of an inch in diameter and 15 inches long, to one end of which is soldered a small brass plumber's union. This inner tube is surrounded by a second thin-walled brass tube $1\frac{1}{4}$ inches in diameter, 11 inches long, which is provided with a two-hole rubber stopper at each end, one hole being for the inner tube. A small brass tube 2 inches long is inserted through the second hole of each stopper to provide connection for the entrance and waste of the water which is circulated between the inner and outer tubes to keep the inner tube cool. The delivery tube from the retort is so bent that when the retort is in an upright position the condenser will be turned at an angle of about 40° from the horizontal. The condenser is held in position by a single clamp, attached to a ring stand.

The receiver for the condensable products of the distillation consists of a 50 cubic centimeter glass graduate, provided with a two-hole rubber stopper through which are thrust two glass tubes, one for the entrance of the liquids and permanent gases from the condenser and the other for the escape of the permanent gases to the ammonia scrubber. The glass tubes have a diameter of about a quarter of an inch and are bent at the proper angles to make connections with the condenser and scrubber. The tubes should barely penetrate the cork.

The ammonia scrubber consists of an ordinary glass cylinder or 8-ounce wide-mouthed bottle, provided with a glass tube reaching nearly to the bottom of the bottle for the entrance of permanent gas from the receiver. The bottle is filled with glass beads, which provide additional surface and a means of breaking up the gas into small bubbles as it passes up through a 10 per cent solution of sulphuric acid.

The water for cooling the condenser may be had from waterworks, or if no running water is at hand a tank or tub may be stationed near the condenser, at a slightly higher level, and the water conveyed over the top by a siphon entering the condenser at the lower end and wasting at the upper end.

The pliers are used for handling the retort.

The postal balance has a capacity of 4 pounds and is used to weigh the sample of shale.

The glass separatory funnel is used to separate the oil from the water derived from the shale.

In order to determine the quantity of oil and ammonia that may be derived from a sample of shale, the shale is first pulverized to pass through a screen of $\frac{1}{2}$ -inch mesh. After thorough mixing a sample weighing $8\frac{1}{2}$ ounces is so selected as to represent the entire quantity. This sample is placed in the iron retort and the cover securely fastened. In order to prevent leaks the joint between the cover and retort bowl is plastered with a thick paste made of a mixture of powdered graphite and glycerine. The delivery tube from the retort is then coupled with the inner tube of the condenser. The ammonia scrubber is filled approximately two-thirds full with a 15 per cent solution of sulphuric acid, and cool water (not ice water) is started circulating through the condenser. The blast lamp is then lighted and placed beneath the retort, with the flame turned as low as possible. After heating about 10 minutes water and oil will begin to condense and be delivered into the receiver. The permanent gas will pass into the ammonia scrubber and bubble up through the sulphuric acid, which will combine with any ammonia contained in it, producing soluble ammonium sulphate. Gentle heat should be applied to the retort as long as any oil is delivered to the receiver; then the flame of the burner may be lengthened until at the end of three or four hours the burner will be at full blast, the retort will be red hot, and the shale will cease to yield either oil or gas. The products of the distillation are then measured; the quantity of oil in the receiver is recorded, as well as the quantity of water in the same receiver. The liquid products of the distillation are then transferred to the separatory funnel and the water drawn off from the oil and added to the liquid contained in the ammonia scrubber. The material contained in the ammonia scrubber is then placed in a glass-stoppered bottle and transferred to a chemical laboratory for the determination of the quantity of ammonium sulphate. The yield of oil in United States gallons to the short ton of shale is equal to the number of cubic centimeters of oil in the receiver, provided the sample of shale used weighs $8\frac{1}{2}$ ounces. The oil obtained from the distillation should be placed in a small bottle for determination of its specific gravity, which can best be done in the laboratory. In order to compute the number of pounds of ammonium sulphate which may be derived from a short ton of shale it is necessary only to multiply the number of grams of ammonium sulphate found in the sample by 8.8.

RESULTS OF TESTS.**SALIENT FEATURES.**

The results of the tests made in the field and in the laboratory at Washington are given below and show variation from a maximum yield of 90 gallons of oil to the ton of shale to a minimum of 0.31 gallon. The yield of ammonium sulphate was not determined for samples tested during the early part of the first season's work, but those which were tested show a range from 18.3 pounds by dry distillation or 34 pounds by steam distillation to 0.4 pound to the ton of shale. Likewise the yield of inflammable gas ranges in the samples for which the amount was recorded from 4,549 cubic feet to the ton of shale to less than 500 cubic feet. Many of the samples that were subjected to destructive distillation were selected not because they were supposed to be rich in oil but in order that the field men might be better able to judge from the appearance of the shale how much oil it would yield when subjected to distillation. Several samples were selected in order to determine the geologic range of oil-yielding shale. All samples were taken near the outcrop, and it is probable that some of the more volatile constituents of the oil had been lost by evaporation, hence the results of distillation tests do not show the maximum amount of oil that may be obtained even by the method of distillation used. The stratigraphic position of nearly all the beds sampled is given in the sections (pp. 170-189).

Results of distillation of samples of oil shale collected in 1914.

Sample No.	Location.		Thickness of shale sampled.	Weight of shale used.	Crude oil obtained (cubic centimeters).		Equivalent yield of oil per short ton of shale (United States gallons).	Gravity of oil at 60° F.		Yield of gas shale per short ton of shale (cubic feet).	Yield of ammonium sulphate per short ton of shale (pounds).	Remarks.
	Sec.	T.	R. W.		Dry.	With steam.		Specific gravity.	Degrees Baume.			
1.	Juab, Utah.	2	9	6 ounces.	8.5	.....	11.9	0.8965	25.6	1.198	2.5	Laboratory test.
2.				6 ounces.	8.5	.....	11.9	.8966	27.9	3.352	2.2	Do.
3.	Mt. Pleasant, Utah	3	0	6 ounces.	8.5	.....	11.9	.8965	26.2	2.525	6.5	Do.
4.	Soldiers Summit, Utah.	6	0	6 ounces.	12.0	.....	16.8	.8937	26.6	2.884	3.5	Do.
5.	Green River, Wyo. ^a	.....	.....	6 ounces.	21.0	.....	29.4	.9130	23.3	2.978	9.0	Do.
6.	Elko, Nev. ^b	.....	.....	6 ounces.	62.0	.....	86.8	.9235	28.2	3.891	6.6	Do.
7.		2	7	85 lbs.	2,040.0	.....	12.6+	.9371	21.6	.....	.....	Field test; retort leaked.
8.		4	8	117 lbs.	946.2	.....	4.26	.9010	19.4	.....	.....	Field test.
9.		3	10	6 ounces.	8.5	.....	11.9	.9138	25.4	2.385	7.1	Laboratory test.
10.		3	10	104 lbs.	2,217.7	.....	11.3	.9290	23.2	.....	.....	Field test.
11.		1	11	130 lbs.	2,040.3	2,454.3	8.22	.8919	20.7	3.034	9.7	Field test; retort leaked.
12.		2	3	150 lbs.	.....	.....	8.64	.9165	22.7	3.034	12.8	Field test.
13.		5	0	6 ounces.	24.0	.....	33.6	.....	.....	.....	.....	Laboratory test.
14.		15	2	6 ounces.	9.5	.....	13.3	.....	.....	.....	.....	Do.
15.		15	2	1 lb.	7.4	.....	3.0	.....	.....	.....	.....	Field test; retort leaked.
16.		15	2	1 lb.	3.7	.....	1.9	.....	.....	.....	.....	Field test.
17.		13	6	6 ounces.	13.0	.....	21.0	.9059	24.8	3.123	18.2	Laboratory test.
18.		3	4	142 lbs.	.....	6,150.6	22.88	.9290	20.7	.....	.....	Field test.
19.		16	2	6 ounces.	1,685.5	.....	6.27	.9327	20.0	.....	.....	Do.
20.		3	4	6 ounces.	9.0	.....	12.6	.9030	25.0	3.512	16.4	Laboratory test.
21.		10	2	6 ounces.	1,685.5	.....	26.8	.....	.....	.....	.....	Field test.
22.		3	5	13 lbs.	11.0	.....	15.4	.9310	20.4	3.592	9.0	Laboratory test.
23.		15	2	6 ounces.	.....	.....	7.61	.9321	20.2	.....	.....	Laboratory test.
24.		2	2	150 lbs.	.....	1,337.6	6.25+	.9352	19.7	.....	.....	Field test.
25.		1	6	15 lbs.	.....	1,360.0	3.85	.9109	23.7	.....	.....	Field test; retort leaked.
26.		9	8	1 lb.	7.4	.....	9.1	.9030	24.1	.....	.....	Do.
27.		18	1	6 ounces.	6.0	.....	13.5	.8946	26.5	1.926	18.3	Laboratory test.
28.		11	1	6 ounces.	10.0	.....	40.6	.9040	24.0	2.075	1.0	Do.
29.		9	4	6 ounces.	22.2	.....	12.5	.9082	24.1	.....	10.5	Field test.
30.		7	4	1 lb.	23.9	.....	9.1	.....	.....	.....	.....	Do.
31.		11	1	1 lb.	20.6	.....	13.5	.8880	27.6	.....	.....	Do.
32.		3	0	6 ounces.	48.1	.....	40.6	.8838	28.4	3.832	8.5	Laboratory test.
33.		11	1	6 ounces.	23.0	.....	25.5	.8820	26.9	.....	.....	Field test.
34.		11	1	6 ounces.	42.5	.....	23.0	.8844	27.6	.....	.....	Do.
35.		11	1	6 ounces.	27.7	.....	31.0	.8864	27.9	.....	.....	Do.
36.		3	3	8 ounces.	29.6	.....	31.0	.8831	28.5	.....	15.8	Do.

37	11	1 N.	97	5	89	1 lb.	44.4	23.25	.8877	27.7	4, 294	6.3	Do. Laboratory test.
38	14	1 S.	97	5	11	6 ounces.	18.0	23.2	.8855	26.4		8.2	Field test.
39	36	1 N.	96	3	0	1 lb.	26.9	13.7	.8896	25.8		4.48	Do.
40	36	1 N.	96	3	8	1 lb.	22.2	12.5	.8859	24.3		4.91	Do.
41	36	1 N.	96	1	4	1 lb.	25.9	13.7	.8803	32.7			Do.
42	29	1 N.	97			10 ounces	3.7	.31					Do.
43	2	3 S.	95	4	9	1 lb.	17.7	9.4	.8897	27.4		5.72	Do.
44	2	3 S.	95	13	6	1 lb.	11.8	6.2	.9025	25.1		3.25	Do.
45	32	4 S.	94	9	1	6 ounces.	4.5	6.1	.9205	22.1	639	2.8	Laboratory test.
46	16	4 S.	94	5	2	1 lb.	22.2	12.5	.9037	23.2			Field test.
47	27	4 S.	94	2	0	6 ounces.	29.6	7.0	.9030	25.4	479	1.7	Field test.
48	27	4 S.	94	4	0	1 lb.	5.0	15.5	.8331	20.0		4	Laboratory test.
49	27	4 S.	94	3	0	6 ounces.	7.5	10.5	.8655	24.4		7.4	Field test.
50	6	6 S.	94	10	0	6 ounces.	29.0	40.6	.8790	23.2	4, 071	4.3	Do.
51	6	6 S.	94	4	3	6 ounces.	20.0	28.0	.9126	23.4	4, 294	7.3	Do.
52	22	6 S.	95	8	8	6 ounces.	17.5	24.5	.8636	32.1	1, 198	4.4	Do.
53	22	6 S.	95	8	6 ounces.	25.0	25.0	35.0	.8802	29.0	8, 500	8.7	Do.
54	22	6 S.	95	8	0	1 lb.	39.5	20.7	.5355	33.1			Field test.
55	22	6 S.	95	13	0	6 ounces.	11.0	15.4	.9070	24.3	1, 443	3.2	Laboratory test.
56	22	6 S.	95	15	0	6 ounces.	8.0	11.2	.9285	21.1	1, 198	4.0	Do.
57	1	7 S.	98			6 ounces.	46.5	65.3	.9115	23.6	4, 549	7.0	Do.

a Hand specimen collected by W. T. Lee.

b Hand specimen collected by D. T. Day.

Results of distillations of samples of oil shale in the field in 1915.

Sample No.	Location.				Thick- ness of shale sampled.	Gravity of oil at 60° F.		Yield of oil per short ton of shale (U. S. gallons).	Yield of ammonium sulphate per short ton of shale (pounds).
	Sec.	T.	R.	State.		Specific gravity.	Degrees Baumé.		
58.....	17	11 S.	25 E.	Utah.....	<i>Ft. in.</i> 3 11	0.8969	25.74	23	5.04
59.....	17	11 S.	25 E.	do.	1 0	.9337	20.10	9	4.59
60.....	17	11 S.	25 E.	do.	2 2	.9019	25.22	12	4.38
61.....	17	11 S.	25 E.	do.	6 7	.9041	24.85	10	3.92
62.....	20	11 S.	25 E.	do.	3 11	.8983	25.85	18	5.37
63.....	20	11 S.	25 E.	do.	4 3	.8998	25.59	32	6.96
64.....	20	11 S.	25 E.	do.	6 2	.8870	27.83	15	4.09
65.....	20	11 S.	25 E.	do.	6 6	.9090	24.01	32	5.45
66.....	20	11 S.	25 E.	do.	6 6	.9052	24.66	65	9.65
67.....	20	11 S.	25 E.	do.	6 6	.8745	30.09	90	6.89
68.....	20	11 S.	25 E.	do.	6 2	.9112	23.64	31	6.99
69.....	20	11 S.	25 E.	do.	3 2	.9021	25.19	19	5.04
70.....	20	11 S.	25 E.	do.	5 9	.9260	21.18	14	4.98
71.....	20	11 S.	25 E.	do.	7 0	.9098	23.88	7	3.48
72.....	20	11 S.	25 E.	do.	6 2	.8775	29.54	7	2.25
73.....	20	11 S.	25 E.	do.	4 8½	.9263	21.13	6	2.61
74.....	20	11 S.	25 E.	do.	5 9	.8887	27.53	32	7.05
75.....	22	11 S.	25 E.	do.	2 4	.9036	24.93	35	5.14
76.....	22	11 S.	25 E.	do.	4 6	.9034	24.97	31	6.20
77.....	26	10 S.	25 E.	do.	6 9	.8727	30.42	37	7.81
78.....	24	11 S.	25 E.	do.	6 3	.8833	28.49	48	9.76
79.....	27	10 S.	25 E.	do.	4 1			1	2.11
80.....	15	10 S.	25 E.	do.	4 7	.9084	23.94	33	5.87
81.....	15	10 S.	25 E.	do.	1 11	.9073	24.30	24	6.72
82.....	15	10 S.	25 E.	do.	6 0	.9163	22.78	20	6.49
83.....	15	10 S.	25 E.	do.	4 0	.8975	25.98	8	5.32
84.....	15	10 S.	25 E.	do.	7 8	.8966	26.14	21	3.77
85.....	15	10 S.	25 E.	do.	1 8	.8879	27.67	22	5.39
86.....	15	10 S.	25 E.	do.	3 2½	.8934	26.70	37	6.52
87.....	15	10 S.	25 E.	do.	1 ½	.8866	27.90	54	5.51
88.....	15	10 S.	25 E.	do.	2 1	.8914	27.05	25	4.05
89.....	15	10 S.	25 E.	do.	4 0	.9059	24.64	17	5.48
90.....	15	10 S.	25 E.	do.	4 8	.8976	25.97	45	9.22
91.....	15	10 S.	25 E.	do.	5 1	.8953	26.37	30	5.35
92.....	9	13 N.	99 W.	Wyoming.	5 0	.8709	30.79	20	3.94
93.....	19	13 N.	103 W.	do.	4 0	.8760	30.81	11	4.88
94.....	25	13 N.	104 W.	do.	2 0	.8937	26.65	15	5.91
95.....	26	13 N.	108 W.	do.	5 0	.9496	17.43	13	7.49
96.....	26	13 N.	108 W.	do.	5 4	.9277	20.91	4	12.99
97.....	26	13 N.	108 W.	do.	4 10	.9062	24.49	6	4.71
98.....	27	13 N.	108 W.	do.	5 0			3	7.18
99.....	27	13 N.	108 W.	do.	3 3½			19	9.32
100.....	27	13 N.	108 W.	do.	5 0			3	9.62
101.....	13	13 N.	108 W.	do.	2 7	.8994	25.65	34	5.70
102.....	13	13 N.	108 W.	do.	4 0	.9060	24.52	15	8.50
103.....	23	14 N.	108 W.	do.	2 11	.8818	28.77	22	6.62
104.....	23	14 N.	108 W.	do.	11	.8892	27.44	30	4.39
105.....	9	14 N.	108 W.	do.	4 2	.8885	27.66	7	2.47
106.....	11	14 N.	108 W.	do.	7 2	.9183	22.45	9	11.14
107.....	36	16 N.	108 W.	do.	5 3	.9022	25.18	21	5.69
108.....	36	16 N.	108 W.	do.	6 0	.8925	26.86	13	5.06
109.....	17	17 N.	106 W.	do.	5 9	.8798	29.12	11	5.51
110.....	17	17 N.	106 W.	do.	6 3	.9190	22.34	19	9.82
111.....	17	17 N.	106 W.	do.	5 4	.9111	23.66	19	8.81
112.....	17	17 N.	106 W.	do.	5 1	.9075	24.26	9	7.59
113.....	17	17 N.	106 W.	do.	5 3	.9050	24.69	10	5.10
114.....	17	17 N.	106 W.	do.	4 6	.9143	23.12	11	3.86
115.....	17	17 N.	106 W.	do.	4 6	.8848	28.22	9	2.28
116.....	17	17 N.	106 W.	do.	4 10			4	3.02
117.....	27	16 N.	106 W.	do.	8 1	.9003	25.50	19	8.68
118.....	27	16 N.	106 W.	do.	5 6	.9120	23.50	14	5.50
119.....	19	17 N.	106 W.	do.	5 0	.8963	26.19	12	7.17
120.....	19	17 N.	106 W.	do.	5 0	.8702	30.88	14	7.98
121.....	16	17 N.	106 W.	do.	4 4	.9456	18.05	14	11.19
122.....	9	17 N.	106 W.	do.	7 3	.9077	24.23	14	4.27
123.....	9	17 N.	106 W.	do.	6 6	.9197	22.22	19	2.74
124.....	8	18 N.	107 W.	do.	5 9	.9027	25.09	13	5.80
125.....	8	18 N.	107 W.	do.	3 3½	.8800	29.09	6	3.73
126.....	8	18 N.	107 W.	do.	1 8	.9182	22.47	20	11.71
127.....	24	18 N.	107 W.	do.	6 3	.9148	23.03	18	7.27
128.....	24	18 N.	107 W.	do.	2 4	.8862	27.97	7	5.65
129.....	5	21 N.	107 W.	do.	1 7	.8705	30.82	8	.99
130.....	5	21 N.	107 W.	do.	5 0	.8837	28.42	10	.86
131.....	5	21 N.	107 W.	do.	2 0	.8889	27.49	50	1.99
132.....			(b)		2 4	.8449	35.70	50	4.50

^a Collected by A. R. Schultz from fissile shale described as Wasatch in U. S. Geol. Survey Bull. 381, p. 222, 1910.

^b Collected by David White from a point near Elko, Nev.

OIL.

Most oils obtained from the distillation of shale are reddish brown, and at ordinary temperatures range from semisolid vaseline-like products to a thin liquid.

Samples 7, 8, 10, 11, 12, 18, 19, 21, 23, 24, and 25 were distilled in the large field retort, and the resulting oils have a specific gravity ranging from 0.9109 (23.7° Baumé) to 0.9371 (19.4° Baumé). The oils obtained from samples distilled in the small apparatus range in specific gravity from 0.8449 (35.7° Baumé) to 0.9496 (17.4° Baumé), though by far the larger number of samples show a specific gravity of less than 0.90 (25.0° Baumé). The difference in the oils obtained by using the large and small apparatus is probably due to conditions of heating rather than to differences in original material, but the oil from all samples distilled in a particular apparatus may be assumed to have been obtained under conditions approximately similar. About one-fourth of the distillations were made in the Washington laboratory of the Bureau of Mines, with an apparatus similar to the small outfit used in the field. In order to compare the tests made in the laboratory with those made in the field with the small apparatus, shale from two samples tested in the field was tested in the laboratory, and the results were found to check very closely.

It was suggested at the beginning of the oil-shale investigations that distillation of shale with the injection of steam into the heated retort might result in a product of increased value, but before 1914 no sample had been treated in such a way that a comparison of the value of dry and steam distillation could be made. The writer therefore during the first field season selected a sample of shale and, after careful mixing, divided the sample into two equal parts (142 pounds each). One part was distilled dry and the other part distilled in the same apparatus on the following day with the addition of steam to the heated mass. From the dry-distilled sample (No. 19) oil was obtained at the rate of 6.27 gallons to the ton of shale; the steam-distilled sample (No. 18) yielded 22.88 gallons of oil to the ton. It is not likely that the larger yield of oil obtained from the second sample could be entirely due to the effect of the steam, and it is probable that to other factors, such as leakage, may in part be due the difference in quantity of oil obtained under the two methods of distillation. That the oil produced by steam distillation is not radically different from that produced by dry distillation is shown by the similar proportion of products which the oils yield on fractionation. (See table, p. 156.) It is unfortunate that in this test, the only one made on a large sample, there was no equipment available to ascertain the effect of steam distillation on the yield of ammonium sulphate. Later, six samples of oil shale were distilled with steam at the Washington laboratory of the Bureau of Mines.

For these samples the quantity of oil derived by steam distillation exceeded that by dry distillation only slightly or in some samples not at all. At the same time the oil produced by steam distillation has a uniformly heavier gravity. The detailed results of these tests are given on page 160.

Oils from nine samples treated in the field and in the laboratory were redistilled with the following results:

Results of fractionation of shale oil.

Sample No.	4	6	10	18	19	27	32	51	57
Begins to boil at °C.....	80	52	50	70	72	65	80	70	54.
Distillation (cubic centimeters):									
To 100° C.....	6	10	2	2.5	2	4	2.5	7	4
100 to 125° C.....	2	.5	3.5	1	1	1.5	3.5	1	2
125 to 150° C.....	2	1.5	6.5	2.5	8	1.5	4.5	1	3
Total gasoline.....	10	12	12	6	11	7	10.5	9	9
150 to 175° C.....	2	2	8	6	6.5	3	6	2	5
175 to 200° C.....	2	4	6	5	5	3	5	4	4.5
200 to 225° C.....	5	4	7.5	5	5	4	6	4	5
225 to 250° C.....	7.5	6	7	5	5	5	6	6	5
250 to 275° C.....	6	6	7.5	7	7	7	8.5	6.5	7
275 to 300° C.....	6	10	13	7	7	17	9	13	12
Total kerosene.....	28.5	32	49	35	35.5	39	42.5	35.5	38.5
Total distillate.....	38.5	44	61	41	46.5	46	53	44.5	47.5
Total residuum.....	61.5	56	39	59	53.5	54	47	51.5	52.5
Amount of oil used.....	100	100	100	100	100	100	100	96	100
Specific gravity at 60° F.:									
Crude.....	0.8937	0.8850	0.9138	0.9290	0.9327	.08946	0.8838	0.9126	0.9126
Gasoline.....	.7947	.7769	.8080	.7974	.8202	.7849	.7568	.7838	.7905
Kerosene.....	.8602	.8466	.8260	.8742	.8976	.8722	.8624	.8632	.8538
Residuum.....	.9695	.9643	.9584	.9594	1.0160	.9684	.9368	.9636	.9626
Asphalt, per cent by weight.	1.35	.82	2.82	4.10	3.62	2.49	.47	1.40	1.08
Paraffin.....do	7.70	6.93	2.22	3.72	1.63	4.56	4.70	9.21	4.00
Sulphur.....do	.54	1.06				.73	1.42	.41	.69
Nitrogen.....do	1.848	.887	2.198	1.549	1.048	1.267	1.849	1.820	2.135
Unsaturated hydrocarbons:									
Crude.....per cent			82	86	81.6		72		
Kerosene.....do	55	55	64	71	71	61	57	63	58

A study of the table reveals a fairly uniform quantity of products from the different samples, the gasoline ranging from 6 to 12 per cent, the kerosene from 28.5 to 49 per cent, the paraffin from 1.63 to 7.70 per cent, and the sulphur from 0.41 to 1.42 per cent. The samples for fractionation were chosen to illustrate both range in physical character of the shale and wide geographic distribution. Sample 4 was from massive shale obtained near Soldier Summit, Utah (for location see Pl. X); sample 6, from brown shale near Elko, Nev.; sample 10, from massive shale in sec. 9, T. 1 N., R. 103 W., Colo. (see Pl. XVIII); samples 18 and 19, from massive shale in sec. 16, T. 2 N., R. 98 W., Colo. (No. 18, steam distilled; No. 19, same sample, dry distilled); sample 27, from papery shale in sec. 11, T. 1 N., R. 97 W., Colo.; sample 32, from massive shale in sec. 11, T. 1 N., R. 97 W., Colo.; sample 51, from massive shale in sec. 6, T. 6 S., R.

94 W., Colo.; sample 57, from massive black shale in sec. 1, T. 7 S., R. 98 W., Colo.

The samples, except No. 27, were obtained within a few inches of the outcrop and probably were slightly weathered, although physical evidence of weathering in the type of shale sampled extends only a very short distance back from the outcrop. As the papery shale weathers to considerable distance back from the outcrop a drift 18 feet long was driven for the purpose of obtaining a sample (No. 27), but the zone of weathering had not been passed at the point of sampling.

In order to determine the behavior of shale oil when subjected to the Rittman process ¹ of refinement, two samples were tested at the Pittsburgh laboratory of the Bureau of Mines. The only samples of shale oil available for these tests were two obtained by Woodruff ² in 1913 from field distillations of shale described below. The samples had remained sealed since the date of original distillation and were therefore probably not greatly altered. Each sample was fractionated in the ordinary way with the following results:

Fractionation of shale oil by ordinary method.

Distillation—	Sample A: Specific gravity, 0.882; boiling point, 32° C.		Sample B: Specific gravity, 0.925; boiling point, 28° C.	
	Percentage by weight.	Specific gravity.	Percentage by weight.	Specific gravity.
To 75° C.	3.4	0.691	2.5	0.700
75° to 100° C.	2.4	.738	1.6	.....
100° to 125° C.	4.8	.754	3.6	.772
125° to 150° C.	5.6	.775	5.5	.792
150° to 175° C.	6.4	.795	5.8	.814
175° to 200° C.	6.6	.821	6.7	.842
200° to 225° C.	6.8	.844	6.1	.862
225° to 250° C.	7.2	.866	6.4	.884
250° to 275° C.	9.4	.892	7.2	.913
275° to 300° C.	8.7	.901	9.0	.929
Residuum	33.5	Solid.	43.0	Solid.

The residuum over 175° C. of each sample (A and B) was then divided into two parts (A and A', B and B') and run in a Rittman furnace with 150 pounds pressure, different temperature being used for each part, as indicated below.

A. Subsurface sample from north side of White River, 5 miles east of White River stage station, T. 9 S., R. 26 E., Utah. Bed, 3 feet 6 inches thick. Yield, 33.3 gallons of oil to the short ton of shale.

B. Sample obtained 4 miles north of Ninemile Creek, approximately in sec. 12, T. 11 S., R. 16 E., Utah. Bed, 6 inches thick. Yield, 39 gallons of oil to the short ton of shale.

¹ Rittman, W. F., Dutton, C. B., and Dean, E. W., *Manufacture of gasoline and benzene-toluene from petroleum and other hydrocarbons*: Bur. Mines Bull. 114, 1916.

² Woodruff, E. G., and Day, D. T., *op. cit.* pp. 4, 19, 20.

Rittman furnace tests on residuum obtained from distillations of shale oil at temperature over 175° C. Pressure 150 pounds (gage reading).

	Sample A.	Sample A'.	Sample B.	Sample B'.
Temperature used (°C.).....	525	550	525	600
Specific gravity of residuum.....	0.920	0.920	0.957	0.957
Specific gravity of recovered oil.....	.901	.902	.929	.909
Percentage recovery.....	79	79	82	70

The oil recovered from the treatment in the Rittman furnace was then distilled with the following results:

Distillation of oil recovered from Rittman tests of shale oil.

	Sample A.	Sample A'.	Sample B.	Sample B'.
Specific gravity of recovered oil.....	0.901	0.902	0.929	0.909
Distillation (per cent by weight)—				
To 75°.....		4.2		3.8
To 100°.....	2.2	6.2	2.8	1.8
100° to 125°.....	1.1	8.5	1.1	2.6
125° to 150°.....	1.4	10.7	1.6	2.7
150° to 175°.....	2.7	13.8	3.0	4.2
175° to 200°.....	7.0	20.0	6.3	6.9

° Distillation, 75° to 100° C.

An examination of the above tables shows that by ordinary methods of fractionation Samples A and B will yield 22.6 and 19.0 per cent, respectively, of distillate up to 175° C. Treatment of the residuum above 175° C. in the Rittman furnace with 150 pounds pressure and temperatures of 525° to 600° C. produces an oil which will yield additional fractions below 175° C. according to the temperature used in the furnace. Tests of two samples of shale oil do not furnish adequate data for generalizations but merely indicate that under proper treatment shale oil may be made to yield a much larger percentage of gasoline than that shown in the tables on pages 156 and 157.

AMMONIUM SULPHATE.

Inasmuch as one of the valuable products derived from the distillation of shale in Scotland is ammonium sulphate, it is interesting to compare the amount of nitrogen in the shale with the amount that is accounted for in the products of distillation. The following table is based on the assumption that all the nitrogen in the shale can be converted to ammonium sulphate:

Relation between total amount of nitrogen in shale and amount accounted for in products of distillation.

Sample No.	Nitrogen in shale.	Theoretical equivalent of nitrogen in ammonium sulphate (per ton of shale).	Yield of oil per ton of shale.	Nitrogen in oil.	Equivalent ammonium sulphate (per ton of shale).	Ammonium sulphate extracted from gas (per ton of shale).	Total nitrogen accounted for in ammonium sulphate (per ton of shale).	Total nitrogen unaccounted for in ammonium sulphate (per ton of shale).
	<i>Per cent.</i>	<i>Pounds.</i>	<i>Gallons.</i>	<i>Per cent.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>
4.....	0.39	36.6	16.8	1.848	10.9	3.5	14.4	22.2
6.....	.39	36.6	86.8	1.887	26.7	6.0	32.7	3.9
27.....	.46	43.2	8.4	1.267	3.7	18.3	22.0	21.2
32.....	.54	50.8	40.6	1.849	26.1	8.5	34.6	16.2
51.....	.46	43.2	28.0	1.820	18.2	7.8	25.5	17.7
57.....	1.22	115.0	65.3	2.135	50.0	7.0	57.0	58.0
63.....	.53	49.9	32.0	(a)	(a)	7.0	(a)	42.9
64.....	.35	33.0	15.0	(a)	(a)	4.1	(a)	28.9
65.....	.73	68.8	32.0	(a)	(a)	5.4	(a)	63.4
66.....	.80	75.4	55.0	(a)	(a)	(a)	(a)	(a)
67.....	1.30	122.5	90.0	(a)	(a)	6.9	(a)	115.6
68.....	.70	66.0	31.0	(a)	(a)	7.0	(a)	59.0
69.....	.32	30.1	19.0	(a)	(a)	5.0	(a)	25.1
74.....	.43	40.5	32.0	(a)	(a)	7.1	(a)	33.4
77.....	.68	64.1	37.0	(a)	(a)	7.8	(a)	56.3
92.....	.60	55.7	30.0	(a)	(a)	3.9	(a)	52.8
101.....	.68	64.1	34.0	(a)	(a)	5.7	(a)	58.4
129.....	.10	9.4	8.0	(a)	(a)	.7	(a)	8.7
131.....	.50	47.1	50.0	(a)	(a)	2.0	(a)	45.1
132.....	.85	80.1	50.0	(a)	(a)	4.5	(a)	75.6

^a Not determined.

^b Nitrogen unaccounted for is much greater in these samples because the amount in oil was not determined.

It will be noticed that in no test has the entire amount of nitrogen present in the shale been accounted for in the products of distillation, and except for one sample (No. 6) there is a larger amount of nitrogen unaccounted for than the amount which was extracted from the fixed gas in the form of ammonium sulphate. In the samples tested the amount of ammonium sulphate extracted from the permanent gas averages 11.1 per cent of the theoretical total amount of ammonium sulphate available from the shale, and an average of 41 per cent of the theoretical total available ammonium sulphate is accounted for by the nitrogen in the shale oil itself. Therefore the theoretically available ammonium sulphate unaccounted for averages more than twice as much as is extracted from the gas produced in the distillation of the shale. In the shale works of Scotland distillation is carried on with the injection of steam, which results, according to Stuart,¹ in practically doubling the amount of ammonium sulphate that is extracted from the permanent gas by the dry method. The table given above indicates that there is ample nitrogen in the shale to allow the extraction of double the amount of ammonium sulphate obtained in the dry distillation, provided the right process is used.

¹ Stuart, D. R., *The oil shale of the Lothians*, 2d ed., p. 144, Scotland Geol. Survey Mem., 1912.

During May, 1916, six samples of oil shale were tested at the Bureau of Mines, with an apparatus similar to that used in the field, but so arranged that superheated steam was injected into the retort during the entire process of distillation. The samples were selected to represent a wide geographical distribution, as well as differences in richness and physical character, and the results of the tests are extremely interesting. Each of the samples had been tested previously in the field apparatus without steam, and the results therefore furnished factors that may be used to convert the results of field tests into what are very probably close approximations to results to be expected from commercial practice.

Comparison of steam and dry distillation.

Sample No.	Oil.				Ammonium sulphate.		
	With steam.		Without steam.		Theoretical yield, equivalent of nitrogen in shale (pounds per ton).	Yield as determined.	
	Yield (gallons per ton).	Specific gravity.	Yield (gallons per ton).	Specific gravity.		With steam (pounds per ton).	Without steam (pounds per ton).
4.....	23.0	0.9346 (19.7° B.)	16.8	0.8937 (26.6° B.)	36.6	13.4	3.5
27.....	10.0	.9135 (23.2° B.)	8.4	.8946 (26.5° B.)	43.2	29.9	18.2
32.....	44.0	.9630 (15.3° B.)	40.6	.8838 (28.4° B.)	50.8	34.0	8.5
51.....	39.0	.9234 (21.6° B.)	28.0	.9126 (23.4° B.)	43.2	15.8	7.3
66.....	55.0	.9286 (20.7° B.)	55.0	.9052 (24.6° B.)	75.4	23.1	9.6
122.....	50.0	.9109 (23.7° B.)	50.0	.8449 (35.7° B.)	80.1	8.4	4.5

The average amount of ammonium sulphate produced from the shale by steam distillation was about two and one-half times the amount obtained from the same samples by dry distillation, thus providing a factor for the conversion of the figure for ammonium sulphate by dry distillation to ammonium sulphate which may be obtained with steam distillation (the method practiced in the oil-shale industry of Scotland and France).

In the six samples tested an average of 37.8 per cent of the nitrogen in the shale was accounted for in the ammonium sulphate obtained by steam distillation, compared with an average of 15.7 per cent recovered by dry distillation. During the two seasons the yield of ammonium sulphate was determined for 57 of the samples that yielded more than 15 gallons of oil to the ton of shale. In these samples an average of 6.7 pounds of ammonium sulphate to the ton was obtained. This multiplied by 2.5, the factor mentioned above, gives an average of 16.7 pounds of ammonium sulphate to the ton, which seems to be a fair estimate of the quantity that may be produced in commercial practice from shale of the area examined in 1914 and 1915.

CHEMICAL ANALYSES OF OIL SHALE.

Shale samples 4, 6, 27, 32, 51, and 57 were analyzed by methods used in making ultimate analyses of coal, with the following results:

Analyses of samples of shale from the Green River formation in Colorado, Utah, and Nevada.

[Made at the Washington laboratory of the Bureau of Mines; J. D. Davis, chemist in charge.]

Sample No.	Location.			Form of analysis. ^a	Proximate.				Ultimate.					Heating value (British thermal units).
	Sec.	T.	R.		Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	
4.....	(b)	.....	.....	A	1.05	33.55	(c)	65.43	0.27	1.80	13.37	0.39	18.74	2,266
				C	.....	33.91	(c)	66.12	.28	1.70	13.51	.39	18.00	2,290
6.....	(d)	.....	.....	A	1.05	45.04	(c)	45.73	1.07	5.19	36.76	.39	10.86	7,714
				C	.....	45.52	(c)	46.21	1.08	5.13	37.15	.39	10.04	7,795
27.....	11	1 N.	97 W.	A	3.18	19.55	(c)	79.00	1.08	1.75	8.34	.46	6.27	1,157
				C	.....	20.19	(c)	81.59	1.12	1.44	8.61	.48	6.76	1,195
32.....	11	1 N.	97 W.	A	.45	37.90	(c)	62.65	.55	2.76	22.48	.54	11.02	4,012
				C	.....	38.07	(c)	62.98	.55	2.72	22.58	.55	10.07	4,030
51.....	6	6 S.	94 W.	A	.43	39.85	(c)	59.95	.30	2.24	18.87	.46	18.18	3,055
				C	.....	40.02	(c)	60.21	.30	2.20	18.95	.46	17.88	3,068
57.....	1	7 S.	98 W.	A	.85	51.60	(c)	46.28	.95	4.32	36.40	1.22	10.38	6,976
				C	.....	52.04	(c)	46.68	.96	4.26	36.71	1.23	10.21	7,086

^a Analysis A represents the composition of the sample as it comes from the ground. Analysis C represents the theoretical condition of the shale after all the moisture has been eliminated.

^b Soldier Summit, Utah.

^c The conditions of heating in the volatile matter determination are different from those in the ash determination, and owing to different reactions the quantity of inorganic residue is not the same in both. As a result, the value of the fixed carbon is for some examples negative.

^d Elko, Nev.

In addition to the ultimate analyses shown above, the percentages of nitrogen and sulphur in 14 samples of shale tested for oil in 1915 were determined, with the following results:

Partial analyses of samples of shale from Utah and Wyoming.

[Made at the Washington laboratory of the Bureau of Mines; J. D. Davis, chemist in charge.]

Sample No.	Location.				Nitrogen.	Sulphur.
	Sec.	T.	R.	State.		
63.....	20	11 S.	25 E.	Utah.....	<i>Per cent.</i> 0.53	<i>Per cent.</i> 0.58
64.....	20	11 S.	25 E.	do.....	.25	.31
65.....	20	11 S.	25 E.	do.....	.73	.70
66.....	20	11 S.	25 E.	do.....	.80	.87
67.....	20	11 S.	25 E.	do.....	1.30	1.59
68.....	20	11 S.	25 E.	do.....	.70	.58
69.....	20	11 S.	25 E.	do.....	.32	.81
74.....	20	11 S.	25 E.	do.....	.43	.42
77.....	26	10 S.	25 E.	do.....	.68	.56
92.....	9	13 N.	99 W.	Wyoming.....	.60	.71
101.....	13	13 N.	108 W.	do.....	.68	1.66
120.....	5	21 N.	107 W.	do.....	.10	.77
121.....	5	21 N.	107 W.	do.....	.80	2.78
132.....	(a)	.....	.....	do.....	.85	5.15

^a Elko, Nev.

GEOLOGY.**THE SHALE.**

The Green River formation, of early Tertiary (Eocene) age, consists predominantly of shale. It exhibits on the weathered outcrop a more or less white color, but closer examination reveals an alternation of gray, bluish gray, and white bands. (See Pls. XI and XIII.) The shale that yields the most oil when subjected to distillation, is that which weathers into massive benches of grayish-blue color but which is dark brown to black on a freshly broken surface. After this tough rich shale, which appears to be without bedding planes or laminations, is heated and the oil driven off it crumbles easily and exhibits true shale structure. Where thin benches of rich shale are interbedded with lean or barren shale, the former, being resistant, weathers to projecting ledges. (See Pl. XIV, A.) Some of the very rich beds show a vitreous luster similar to that of coal. The massive shale (Pl. XVI, A) is exceedingly tough, resists erosion to a remarkable degree, and as it weathers to a bluish-white surface and will burn when ignited the ranchers of some parts of the region refer to it as "white rock that will burn." When freshly broken, the shale gives off an odor of petroleum. All gradations exist between this hard, tough, massive rock and the papery shale (Pl. XVI, B), which weathers to curly forms. The papery shale is in a few places black, but usually light brown, and the thin plates of weathered shale are remarkably flexible, a characteristic which distinguishes it from ordinary carbonaceous shale. Weathering affects the papery shale to a distance of more than 20 feet back from the outcrop, but, except along joint planes, the hard, massive shale shows little evidence of weathering for more than a quarter of an inch from the exposed surface. Oil has been distilled from the papery shale as well as from the hard, massive variety, although in smaller quantity.

The hard, rich shale that crops out as projecting ledges and weathers to a gray or grayish-blue color is dark brown to black on the unweathered surface, and in all probability weathering does not affect the oil-yielding capacity of the shale to any considerable depths. Most of the samples for distillation were taken after chipping away the part of the bed that had been changed from dark to light color, and for most of the samples this required the removal of only an inch or two of weathered shale. In order to determine the difference between the shale just back of this obviously weathered zone and that a foot or so deeper samples 65 and 66 were taken from a single bed near Watson, Utah. Plate XIV, B, shows the relative position of the materials for the two samples, as well as the manner in which the fresh shale breaks when mined. Sample 66 was obtained after blasting away an average of about 18 inches of outcrop shale; sample

65 was taken within an inch or two of the weather-exposed face. The yield of oil for sample 65 was at the rate of 32 gallons to the short ton, but sample 66 gave nearly twice as much, or 55 gallons of oil to the ton.

Inasmuch as the samples of shale for the tests listed on pages 152-154 were obtained near the outcrop, like sample 65, it is safe to assume that the results given in this paper do not represent the maximum yield that may be obtained from the same shale when it is mined.

Although oil may be obtained from the shale by destructive distillation, it does not appear that more than a small percentage exists in the shale as oil; at least oil has not been found in commercial quantity in two wells that have been drilled into the shale in northwestern Colorado. The "gas well" in sec. 22, T. 1 N., R. 97 W., is about 400 feet deep, and develops a strong flow of artesian water, together with considerable gas, but no oil. This well does not reach the richest shale beds. Another well, drilled to a depth of 1,345 feet in sec. 30, T. 2 S., R. 94 W., apparently passes through the Green River formation and penetrates the underlying Wasatch formation, but develops only a show of oil, and that apparently near the contact between the two formations. A spring in sec. 14, T. 1 N., R. 97 W., east of Piceance Creek, issues from between two rich beds of shale. The water is of excellent quality and does not show any evidence of oil or gas.

The following description of the microscopic structure of the shale was furnished by Charles A. Davis, who at the time of his death was engaged in making a careful study of the rocks with special attention to their fossil content:

The shale as seen under the microscope varies as greatly in appearance and structure as it does when examined with the unaided eye, according to the locality and bed from which the material examined originally came. The darker specimens yield sections showing characteristic opacity, density, and compactness of structure and fineness of grain. The lighter-colored samples show less opacity and appear more granular, even when casually examined. Specimens from the same sample also present quite different appearances, according to the direction in which the section is cut.

Under low powers of the compound microscope sections cut transverse to the bedding planes show a more or less distinct lamination or banded structure, the dark-brown to light-yellow bands alternating irregularly with colorless or light-grayish ones. Usually the dark bands of the section are longer and more continuous than the light bands.

Under higher magnifications these bands resolve themselves into a series of more or less discontinuous thin laminae, of which the brown and yellow or dark ones are certainly longer and more continuous than the gray or colorless ones. Careful inspection shows that the dark laminae are usually not easily resolvable into granules, while the light ones are obviously made up chiefly of particles of crystals of mineral matter; much of the mineral matter is very finely divided, although some sand is present. Moreover, most of the laminae containing mineral matter are lens-shaped, and in the samples in which they were carefully examined many of them were found to

be from two to eight or ten times as long as they are thick, and the darker laminae in the same sections are characteristically many times longer than they are thick.

In addition to these general characteristics shown in the cross sections the samples exhibit the following features:

1. Well-marked openings, in places of polygonal or even square outline, but more commonly of irregular lens shape or the shape of a flattened sphere. The larger of such openings occur usually in the lenses of mineral matter that is in the form of coarse particles. Some of these openings still contain bits of crystalline minerals, and others contain fine silty residues. It is thus evident that the openings themselves may have been formed by the breaking up of the original filling, which corresponds to that of the shorter, lens-shaped laminae, during the cutting of the section.

2. Irregularly distributed black opaque bodies, which glisten by reflected light. These fill lenslike openings that seem identical with those just described, as well as other openings, including the irregularly polygonal matrices of minerals. The material forming the opaque bodies only partly fills some of the openings in which it occurs. Such partly filled spaces show by their irregular filling and by the relation of the opaque matter to included minerals that they have been filled by local intrusion from the surrounding walls, as the material has not yet been observed running from one cavity to another, and unfilled cavities are numerous near and between those that are filled.

3. Very dark brown or black lines, which seem to represent the edges of vegetable structures such as fibers, filaments, or films that are of different composition or are more fully carbonized than the general mass of material with which they were laid down. These dark lines are in places interlaminated with light-colored organic matter and clearly can not be considered as intrusions into the laminated material after it was laid down, as the whole series of laminae is in places very finely wrinkled and each individual layer is of extreme thinness, many being less than a micron thick. As these very thin light-colored laminae are entirely conformable with the thinnest dark ones, they must have been laid down with them. The thicker dark laminae, being more opaque than the light ones, can not be so readily resolved for measurement, but where they have been carefully studied they show minute secondary lamination as well as the inclusion of thin lines of inorganic sediment, a structure which clearly proves their sedimentary origin and entirely undisturbed condition.

The wide range of variation in the characteristics of the structure, bedding, and grain of the different samples of shale examined makes it impossible to discuss all the variations which have been found, but the points brought out are the most striking ones noted in examining the cross sections.

A study of sections made parallel with the bedding planes of the oil-yielding shale shows also a large number of variations, even in the same fragment. The dark samples in general give the most interesting sections, the lighter-colored ones showing chiefly finely divided amorphous particles of mineral matter, mixed with crystalline particles, which are possibly of secondary origin, and with scattered fragments which from their color and structure are easily recognizable as of organic origin—that is, derived from the remains of plants or animals.

The examination of a large number of horizontal sections shows that the laminae are not generally flat or perfectly horizontal, but rather occur in undulating bands, apparently formed while the material was still in the process of deposition. Some horizontal sections of darker samples show only slightly granular or nearly homogeneous texture, with no inclusions. Other sections show a large number of minute plants and plant remains that are surprisingly well preserved. In general, these plant remains are embedded in the same sort of material of which the seemingly structureless sections are composed. Some of this structureless material can be resolved by careful manipulation to show a granular structure, and under such conditions the shadowy outlines of plant remains can be seen in some sections.

The inference is clear that the structureless material probably originated in a collection of plant débris which has by decomposition and the activities of bacteria and other microscopic organisms passed into a jelly-like phase such as is to be found in certain kinds of modern peat deposits. The plant remains that have been found in the shale from every locality which has furnished samples are those of microscopic algae mixed in smaller percentage with pollen and similar parts of higher plants. Animal remains are rare in the material studied, and those noted were chiefly the remains of insects in a very fragmental state.

It seems apparent, therefore, that the study of the microscopic structure of this shale as seen in vertical and horizontal sections leads to the conclusion that the material was laid down originally in water and that it passed through a series of stages of decomposition before consolidation and lithification had taken place. The remarkably well preserved state of the delicate plant structures which have been examined indicates very slight disturbances of the original material and an almost entire lack of changes produced by the action of the usual metamorphosing agencies since lithification.

STRATIGRAPHY.

The oil-yielding shale is confined almost entirely to the middle part of the Green River formation, and during the present examination little attention was paid to rocks of other formations. In northwestern Colorado the Green River formation is the youngest present, but north of White River and only a few miles west of the Colorado-Utah line the Bridger formation rests unconformably on the Green River as well as older formations, and along the northern edge of the Uinta Basin in Utah the Bridger obscures the entire outcrop of the oil shale. The Bridger formation also occupies the central part of the Green River basin in southwestern Wyoming and west of Burnt Fork and south of Carter overlaps the Wasatch formation, covering the outcrop of the Green River.

The Green River formation is underlain by the Wasatch and this in turn by the Mesaverde, which in Colorado and Utah is coal bearing. The Wasatch in Wyoming contains valuable beds of coal, which may be needed for fuel when the shale-oil industry is developed.

The Green River formation has a maximum thickness near the mouth of Piceance Creek of about 2,600 feet and may be separated there on the basis of the presence or absence of oil-yielding shale into three fairly distinct parts. The upper and lower parts of the formation are practically barren, but the middle part of the formation contains, at every locality examined, beds of shale that will yield considerable oil. A single test was made of shale from the upper division of the formation, which yielded 0.31 gallon of oil to the ton of shale (sample 42, p. 153). The section measured near the mouth of Piceance Creek (H, pp. 177-178) shows the oil-yielding part of the formation to be 1,550 feet thick, whereas the lower barren part is only 342 feet thick and the upper barren part 716 feet thick. According to measurements made near Morris station (O, p. 182) on the Book Cliffs, the upper 595 feet of the section there exposed is

oil yielding, but the underlying part, 1,487 feet thick, includes no beds that will yield any appreciable quantity of oil. The great thickness of lower barren beds near Morris corresponds very closely with the thickness of the lower part of the formation as described by Woodruff¹ in a section measured along the Mount Logan trail in sec. 26, T. 7 S., R. 97 W., only a few miles to the west and on the same general cliff. In general the lower member of the Green River formation is extremely variable both in thickness and character. Along Evacuation Creek, near Dragon, Utah (sec. Q, pp. 183-184), this member includes about 600 feet of coarse sandstone, oolite, and shale with no persistent bed and some very remarkable lenticular beds. Only a few miles away, in Hells Hole Canyon, northwest of Watson (sec. T, pp. 185-186), the lower part of the Green River formation includes largely shale with comparatively thin sandstone beds and only a little oolite.

In contrast to this extreme irregularity in the lower part of the formation the thin beds of the oil-yielding portion are remarkably persistent. Sections Q, S, and T, representing the strata exposed at three places in eastern Utah, separated from one another by 5 and 7 miles (see Pl. XVIII), show three thin beds of sandstone which are remarkably regular in thickness, and at the same time the interval between them varies only slightly from place to place.

The line between the Wasatch and Green River formations is very difficult to follow because of lack of exposures and very hard to identify accurately from place to place. There seems to be a general gradation from the upper part of the Wasatch formation into the lower part of the Green River, and it is possible that the correlations shown on Plate XVII are not absolutely correct.

The Green River formation consists principally of shale but contains, especially in its lower part, beds of sandstone, many of which are ripple marked. Most sections show one or more beds of oolite and some conglomerate or conglomeratic sandstone. Near the old Black Dragon mine, Utah, however, the lower part of the formation, according to measurements made by Woodruff,² contains oolite and sandstone equal to more than half of the exposed thickness of beds (529 feet). There is at the base of the upper part of the formation on Yellow and Piceance creeks a bed of massive brown sandstone which may be equivalent to the Tower sandstone of Powell³ in southwestern Wyoming. As is shown by the sections given below, there are in nearly every section many beds of shale that will yield at least 15 gallons of crude oil to the ton, but the correlation of beds from one measured section to another, although the sections may be

¹ Woodruff, E. G., and Day, D. T., *op. cit.*, p. 14.

² *Idem*, pp. 16, 17.

³ Powell, J. W., *Geology of the eastern portion of the Uinta Mountains*, pp. 40-45, U. S. Geol. and Geog. Survey Terr., 2d div., 1876.

only a few miles apart, is very uncertain. A careful study of the strata exposed in a continuous cliff face a mile or more in extent shows that although the formation appears to be remarkably regular in thickness, individual beds vary greatly from place to place and that a single massive bed 5 feet thick at one place may change to comparatively thin-bedded shale within less than half a mile. Study of any single bed at several places along its outcrop to determine its variability in thickness, bedding; mode of weathering, and value as a source of oil was made impossible by lack of exposures except near the mouth of Piceance Creek in Colorado and along the west side of Green River in southwestern Wyoming. In the Colorado locality a zone of oil-producing shale was examined, carefully measured, and sampled at three localities within a distance of approximately 1,100 feet along its outcrop with the following results:

Sections of oil-shale zone along the west side of Piceance Creek, Colo., in sec. 11, T. 1 N., R. 97 W.

Location 34.

	Ft.	in.		Ft.	in.
Shale, hard, black.....	1	2	Shale, brown, lean ²	2	
Shale, light brown.....	3		Shale, hard, dark.....	3	
Shale, dark brown.....	2		Shale, brown.....		$\frac{1}{2}$
Shale, light brown.....	1		Shale, hard, dark.....	1	
Shale, hard, black.....	7		Shale, lean.....	4 $\frac{1}{2}$	
Shale, light brown.....	$\frac{1}{2}$		Shale.....	1	
Shale, hard, black, in beds 2			Shale, hard, black.....	1	2
inches thick.....	6				
Shale, brown.....	2 $\frac{1}{2}$			5	4
Shale, hard, dark.....	2				

Location 35, 100 feet N. 7° E. of location 34.

	Ft.	in.		Ft.	in.
Shale, dark brown.....	2		Shale, hard, brown.....	2	
Shale, hard, dark brown.....	2		Shale, rich.....	3	
Shale, hard, black.....	1 $\frac{1}{2}$		Shale, hard, brown.....	1 $\frac{1}{2}$	
Shale, sandy, lean.....	1	4	Shale, brown, lean.....	3	
Shale, brown, rich.....	5				
Shale, hard, brown.....	3			4	2
Shale, brown, rich.....	11				

Location 36, about 1,000 feet N. 10° E. of location 35.

	Ft.	in.		Ft.	in.
Shale, hard, dark.....	1		Shale, hard, black.....	8 $\frac{1}{2}$	
Shale, brown, thin bedded.....	1		Shale, brown.....	$\frac{1}{2}$	
Shale, hard, dark.....	4 $\frac{1}{2}$		Shale, hard, black.....	4 $\frac{1}{2}$	
Shale, lean.....	$\frac{1}{2}$		Shale.....	1	
Shale, hard, black.....	5 $\frac{1}{2}$		Shale, hard, black.....	3	
Shale, brown.....	$\frac{1}{2}$		Shale, brown, lean.....	4	
Shale, hard, black.....	4				
Shale, brown.....	1 $\frac{1}{2}$			3	3 $\frac{1}{2}$

¹ Location numbers correspond to those used on the maps. Stratigraphic sections are arranged so that the youngest beds are described first and successively older beds follow.

² In this paper the term "lean" is applied to shale that will yield less than 15 gallons of oil to the short ton and "rich" to shale that will yield more than 15 gallons.

Samples from these localities when subjected to distillation gave the following results:

Results of distillation of samples from three localities on a single bed of shale on the west side of Piceance Creek, sec. 11, T. 1 N., R. 97 W.

Location No.	Total thickness sampled.	Yield of oil per ton of shale.	Gravity of oil.
	<i>Ft. in.</i>	<i>Gallons.</i>	
34.....	5 4	23.0	0.888 (27.6° B.)
35.....	4 2	14.7	.887 (27.9° B.)
36.....	3 3½	31.0	.883 (28.5° B.)

This zone contains shale which on weathering resembles somewhat closely a massive bed but which may be subdivided upon close examination into a number of very thin units differing from one another only in minor particulars. The gravity of the oil derived from these samples is fairly uniform, but the quantity differs widely. It is possible that part of this difference in yield may be due to changes produced by weathering, although if such were the case it would seem that the gravity of the oil in sample 35 would show a corresponding increase. However, the data at hand are not sufficient to make generalizations.

Along both sides of Green River, Wyo., in Tps. 13 and 14 N., R. 108 W., a single bed or zone of rich oil-yielding shale is exposed in almost continuous outcrop for several miles. The bed is made up of alternating thin benches of rich and lean shale which weather into a most characteristic form, so that the bed can be easily identified from place to place. The richer benches weather to grayish-blue ledges which project beyond the softer lean shale, as shown in Plates XIII, *B*, and XIV, *A*. In places slabs 3 or 4 feet square and only an inch thick have weathered out and lie scattered over the surface. The four sections given below illustrate the variability of the different parts of the bed. The results of the field distillations of samples taken at three of the places are given in a separate table following.

Sections of shale bed along Green River, Wyo.

Location 99, sec. 27, T. 13 N., R. 108 W.

	<i>Ft. in.</i>		<i>Ft. in.</i>
Shale, hard, black, rich.....	½	Shale, soft, brown, lean.....	1 8
Shale, soft, brown, lean.....	5	Shale, hard, black, rich.....	3
Shale, hard, black, rich.....	1		
Shale, soft, brown, lean.....	8		3 3½
Shale, hard, black, rich.....	2		

*Sections of shale bed along Green River, Wyo.—Continued.***Location 101, sec. 13, T. 13 N., R. 106 W.**

	Ft. in.		Ft. in.
Shale, hard, black, rich.....	5	Shale, thin bedded, brown, lean...	4
Shale, thin bedded, brown, lean...	2	Shale, hard, black, rich.....	5
Shale, hard, black, rich.....	10		
Shale, thin bedded, brown, lean..	3		2 7
Shale, hard, black, rich.....	2		

Location 102, sec. 23, T. 14 N., R. 106 W.

	Ft. in.		Ft. in.
Shale, thin bedded, brown, lean..	5	Shale, hard, black, rich.....	1 5
Shale, hard, black, rich.....	1 1		
Sandstone.....	1		3 0

Location 105, sec. 9, T. 14 N., R. 106 W.

	Ft. in.
Shale, brownish, black, thin bedded, lean; not sampled.....	2 4

Results of distillation of samples of shale from three localities along the outcrop of a single bed in Tps. 13 and 14 N., R. 106 W., Wyoming.

Location No.	Total thickness sampled.	Yield of oil per short ton of shale.	Gravity of oil.	Yield of ammonium sulphate per short ton of shale.
	Ft. in.	Gallons.		Pounds.
99.....	3 3½	19	Not determined.	9.2
100.....	2 7	34	0.8994 (25.65° B.).	5.7
103.....	3 0	32	.8818 (28.77° B.).	6.6

In many places massive beds of dark, tough, rich shale contain lenses of coarse sand that show no free oil. In other places small masses (some of them mere films between beds) of solid black hydrocarbon are found in the shale. Hydrocarbon occurring in this way in a small gulch east of Piceance Creek near its mouth possesses all the properties of elaterite, but in most places the material is similar to gilsonite. In sec. 14, T. 1 N., R. 97 W., this elaterite may be seen at a number of places between two beds of rather rich shale. In some places, such as Hay Gulch, in sec. 36, T. 1 N., R. 96 W., there are pockets of black material which have the shape of partly compressed stems but which show no woody structure, as would be expected if they were carbonized wood. The material contained in these pockets is not soluble in ether, chloroform, gasoline, or turpentine, the ordinary solvents of hydrocarbons.

Fossil remains, except those of microscopic size, are scarce but include leaves, fresh-water shells, insects, and fish remains. None of the fossils collected were found to be especially diagnostic, although several were identifiable. The shells were collected near the base of

the formation, as were most of the fish and leaf remains, but excellently preserved remains of insects (*Diptera larvæ*, etc.) were found at a number of horizons in the oil-yielding portion of the formation.

The following stratigraphic sections were measured at places indicated on the map (Pl. XVIII), and illustrate the character of the rocks exposed in different parts of the field. The beds of shale that are known by testing or are estimated to yield 15 gallons of oil or more to the ton of shale are indicated by heavy type in the sections.

Sections in northwestern Colorado.

Location A, T. 2 N., R. 104 W.

	Ft.	in.		Ft.	in.
Shale, gray, with a few hard sandstone beds each a few inches thick.....	350	0	Shale, sandy.....	24	0
Sandstone, white.....	1	0	Sandstone, ripple marked; ripples 4 inches from crest to crest and three-quarters of an inch deep.....	3	0
Shale, gray.....	60	0	Shale, sandy.....	10	0
Sandstone, clayey.....	15	0	Sandstone, friable, with about 10 per cent of shale; sandstone is oolitic.....	3	0
Shale, thin bedded, with a few thin beds of sandstone.....	15	0	Sandstone, friable, with about 33 per cent of shale.....	54	0
Shale, brown to black, contains thin beds of rich oil shale.....	2	0	Sandstone, thin bedded.....	15	0
Shale, thin bedded, slightly carbonaceous, but is supposed to yield very little oil.....	30	0	Shale, gray.....	25	0
Shale, brown, thin bedded, will probably yield some oil.....	1	0	Sandstone, shaly.....	1	0
Shale, brown, will probably yield some oil.....	2	0	Shale, sandy.....	15	0
Shale, gray, thin bedded.....	18	0	Sandstone, coarse grained.....	3	0
Shale, thin bedded, brown, contains thin laminae of oil shale.....	10	0	Shale.....	75	0
Shale, sandy.....	40	0	Oolite with grains as large as one-sixteenth of an inch; this stratum is a massive ledge maker, the most resistant rock of the formation.....	5	0
Shale, dark brown, rich in oil.....	4		Shale, sandy.....	62	0
Shale, light gray, sandy.....	7	0	Sandstone, thin bedded.....	5	0
Shale, will yield a little oil.....	1	0	Shale, gray, mostly covered.....	114	0
Shale, gray.....	2	0	Sandstone, thin bedded, cross bedded, and slightly conglomeratic; the grains are mostly silica and well rounded.....	10	0
Shale, dark brown, rich in oil.....	4		Shale, gray.....	50	0
Shale, slightly sandy.....	7	0	Sandstone, conglomeratic; largest pebbles observed have a maximum diameter of one-half inch.....	3	
Sandstone and shale; sandstone shows ripple marks as much as 6 inches from crest to crest.....	15	0	Shale, gray.....	26	0
Sandstone, coarse, containing concretions.....	3	0	Sandstone, shaly.....	3	0
Sandstone, clayey.....	5	0	Shale, gray.....	20	0
Shale, sandy.....	50	0	Surface covered, supposed to be mostly shale; tan-colored shale exposed at base.....	280	0
Sandstone and shale, about 60 per cent sandstone; sandstone for the most part ripple marked; one thin bed of carbonaceous shale.....	90	0	Sandstone, white, lenticular.....	3	0
Sandstone, conglomeratic at the base; most of the pebbles are flat; some are 4 inches across.....	2	0	Shale, drab, contains some sand.....	204	0
Sandstone, thin bedded, not resistant....	15	0	Sandstone, tan-colored.....	6	
			Shale, sandy.....	120	0
			Sandstone, tan-colored, definitely Watsch; bottom of section.....		
				1,872	5

Sections in northwestern Colorado—Continued.

Location B, T. 1 N., R. 103 W.

	Ft.	in.		Ft.	in.
Shale, evenly thin bedded, with very little sandstone.....	250 ±		Shale, sandy.....	7	0
Shale, dark, thin bedded, estimated that at least 50 per cent is oil-bearing shale (sample 10 from bed 3 feet 10 inches thick near top; 11.3 gallons).....	50	0	Sandstone, even bedded.....	2	0
Shale, sandy, thin bedded, lean.....	11	0	Shale, grading into sandstone at the top.....	7	0
Sandstone.....	4		Shale, dark brown, with disseminated iron sulphide, rich.....	1	0
Shale, thin bedded, sandy in places, bituminous in others, will yield some oil.....	7	0	Shale, sandy at base, thin bedded at top.....	9	0
Shale, dark brown, weathers bluish gray, rich.....	7		Sandstone, thin bedded.....	3	0
Sandstone, shaly.....	5	0	Shale, sandy.....	9	0
Sandstone, friable, weathers to round forms.....	1	0	Shale, thinly laminated, dark brown on fresh surface; contains beds of rich shale.....	7	0
Shale, hard, dark brown, (sample rich.....) 8; 4.26 gallons.....	1	0	Shale, sandy.....	2	0
Shale, light brown.....	3	8	Shale, thinly laminated, dark brown on fresh exposure; probably will yield some oil.....	8	0
Shale, alternating beds of rich oil-bearing shale (estimated 10 per cent) and lean shale.....	7	0	Shale, dark brown, thin bedded, rich.....	1	0
Shale, clayey, containing thin beds of rich oil shale.....	4	0	Shale, sandy.....	13	0
Shale, thin bedded.....	6	0	Sandstone, thin bedded, ripple marked.....	2	0
Shale and sandstone, containing some oil-bearing layers; the entire member is colored red by burning.....	45	0	Shale, sandy; in places will yield oil.....	4	0
Shale, sandy; contains some thin sandstones.....	5	0	Shale, dark brown; weathers bluish gray; rich.....	2	
Shale, sandy.....	10	0	Shale, sandy.....	7	0
Shale, dark brown, hard; weathers bluish gray; rich.....	1	0	Sandstone, thin bedded, with some shale.....	7	0
Shale, clayey, thin bedded; contains a few thin layers of rich shale.....	19	0	Shale, lean.....	18	0
Shale, sandy.....	3	0	Sandstone, cross-bedded at top.....	3	0
Shale, thin bedded, clayey.....	8		Sandstone and shale.....	25	0
Shale, sandy; contains some bituminous matter.....	1	0	Sandstone, in beds having a maximum thickness of 4 inches.....	5	0
Shale, with thin beds of rich oil-bearing shale; estimated that 50 per cent is rich rock.....	4	0	Shale, with some sandstone; shale is dark and carbonaceous; probably will yield some oil.....	33	0
Shale, sandy.....	11	0	Conglomerate; maximum size of pebbles half an inch.....	8	
Shale, dark brown; weathers bluish gray; rich.....	2	6	Shale, drab.....	25	0
Shale, sandy, thin bedded, calcareous.....	4	0	Shale, brown; slight oily odor.....	4	
Shale, carbonaceous; contains beds of rich shale as thick as three-quarters of an inch (sample 12; 8.64 gallons).....	2	3	Shale, dark brown; weathers blue.....	11	
Sandstone, ripple marked at top, thin bedded.....	7	0	Shale, light brown; weathers platy.....	5	
Shale.....	3	1	Shale, dark brown, hard; weathers blue.....	2	
Shale, lean.....	1	11	Shale, soft, brown; weathers into fine laminae and curls on surface.....	1	0
Shale, dark brown; contains disseminated iron sulphide (sample 11; 8.22 gallons).....	1	11	Shale.....	50	0
Shale, thin bedded, brown.....	9		Oolite.....	4	
Shale, sandy.....	6	0	Sandstone and shale.....	25	0
Shale, dark brown, massive, rich.....	4	0	Oolite.....	6	
Shale, gray, lean; contains some bituminous matter.....	4	0	Shale and sandstone in layers as thick as 6 inches.....	40	0
Sandstone, thin bedded.....	5	0	Shale, finely laminated; gives slight oily odor when broken.....	8	0
			Sandstone, calcareous.....	6	
			Shale; lower part drab; upper part weathers curly.....	13	0
			Limestone.....	2	
			Shale, mostly drab, partly carbonaceous, finely laminated.....	33	0
			Shale, thin bedded, rich; gives slight oily odor when freshly broken.....	5	0

Sections in northwestern Colorado—Continued.

Location B, T. 1 N., R. 103 W.—Continued.

	Ft.	in.		Ft.	in.
Sandstone, containing clay balls.....		2	Shale, thick bedded, rich; gives oily odor when broken.....	3	0
Shale, drab.....	25	0	Shale.....	12	0
Shale, sandy.....	3	0	Sandstone, coarse grained.....		2
Sandstone, containing pebbles as large as half an inch in diameter.....		2	Shale.....	10	0
Shale, sandy.....	1	6	Sandstone.....		5
Shale, dark brown, rich; gives oily odor when broken.....		4	Shale, thinly laminated, dark brown...	3	0
Shale, thick bedded, rich.....	2	10	Talus slope at bottom.....		
Shale, finely laminated, brown, carbonaceous.....	2	6		929	1½

Location C, on north side of White River, T. 1 N., R. 104 W.

	Ft.	in.		Ft.	in.
Shale, sandy; weathers to round forms...	50	0	Shale.....	5	0
Shale, light brown, lean.....		6	Shale, dark brown; weathers bluish gray; rich.....	1	0
Interval, probably sandy shale.....	20	0	Shale.....	9	0
Shale, dark brown; weathers bluish gray; rich.....		6	Shale, sandy; about 33 per cent rich, dark brown.....	13	0
Shale.....	7	0	Shale, sandy.....	3	0
Shale, dark brown; weathers bluish gray; rich.....	1	0	Shale, dark brown; weathers bluish gray; rich.....	2	0
Shale.....	3	0	Shale, dark brown; weathers bluish gray; rich; and sandy shale.....	1	0
Shale, dark brown; weathers bluish gray; rich.....		6	Shale, sandy.....	3	0
Sandstone, thin bedded.....	15	0	Shale, dark brown; weathers bluish gray; rich.....	1	0
Shale, dark brown; weathers bluish gray; 75 per cent rich shale and 20 per cent lean shale.....	8	0	Shale, drab, with thin layers of rich dark-brown shale.....	3	0
Shale, dark brown; weathers bluish gray; rich.....		8	Shale, dark brown; weathers bluish gray; rich.....		6
Shale, brown, thin bedded.....	1	4	Interval, probably mostly shale.....	13	0
Shale, dark brown; weathers bluish gray; 75 per cent rich shale and 25 per cent lean shale.....	5	0	Shale, dark brown; weathers bluish gray; rich.....	1	0
Shale, dark brown; weathers bluish gray; about 10 per cent lean shale, remainder rich shale.....	5	0	Shale, sandy.....	5	0
Shale, dark brown; weathers bluish gray; about 40 per cent rich shale.....	35	0	Sandstone.....	3	0
Shale, dark brown; weathers bluish gray; about 10 per cent lean shale, remainder rich shale.....		1	Shale.....	7	0
Shale.....	3	0	Shale, dark brown; weathers bluish gray; rich.....		1
Shale, dark brown; weathers bluish gray; about half rich shale and half lean shale.....	3	0	Shale.....	4	0
Shale, sandy.....	4	0	Shale, dark brown; weathers bluish gray; rich.....	1	2
Shale, dark brown; weathers bluish gray; rich.....		6	Shale.....	35	0
Sandstone, massive.....	1	6	Sandstone, shaly.....	4	0
Shale, dark brown; weathers bluish gray; rich and lean shale interbedded.....	5	0	Shale, light gray, sandy.....	4	0
Shale, sandy.....	23	0	Shale; black; contains thin beds of rich dark-brown shale.....	1	0
Sandstone, thin bedded.....	2	0	Shale, drab, with some thin beds of rich dark-brown shale near top.....	20	0
Shale.....	20	0	Shale, dark brown; weathers bluish gray; rich; interbedded with lean shale.....	3	0
Shale, dark brown; weathers bluish gray; rich; contains an abundance of iron pyrite.....	1	0	Shale, thin bedded; 25 per cent rich dark-brown shale.....	6	0
Shale; about 25 per cent rich, dark brown	2	0	Shale, dark brown; weathers bluish gray; rich.....	2	2
Shale, dark brown; weathers bluish gray; rich.....	2	0	Shale, with thin beds of rich dark brown shale.....		6
			Shale, dark brown; weathers bluish gray; rich.....	1	0
			Sandstone, shaly, grading to shale in the lower part.....	8	0

Sections in northwestern Colorado—Continued.

Location C, on north side of White River, T. 1 N., R. 104 W.—Continued.

	Ft. in.		Ft. in.
Shale, dark brown; weathers bluish gray; rich.....	1	Oolite, with grains as large as one-eighth inch in diameter.....	5
Shale, drab.....	27 0	Shale, with some rich dark-brown shale..	5 0
Sandstone, shaly.....	5 0	Oolite.....	1
Shale, sandy.....	23 0	Shale, sandy, with some sandstone.....	13 0
Shale, drab.....	20 0	Oolite.....	1
Shale, thin bedded, black on fresh surface, rich.....	4 0	Shale, upper part tan-colored, lower part gray.....	100 0
Shale, sandy.....	5 0	Sandstone, light colored, with shaly layers and some rich dark-brown shale....	4 0
Shale; weathers curly; will yield some oil.....	6	Shale, light colored at bottom, dark at top; some rich dark-brown shale.....	27 0
Shale.....	18 0	Sandstone, including clay balls; a single fossil gastropod was found in this bed..	4
Sandstone, shaly.....	5 0	Shale, drab.....	2 0
Shale.....	8 0	Sandstone, at some places oolitic and at others slightly conglomeratic.....	8
Sandstone, brown.....	2	Shale, dark.....	20±
Shale.....	20 0	River.....	
Shale, dark brown; weathers bluish gray; rich.....	1 0		
Shale, gray, sandy at base, thin bedded at top.....	75 0		765 3.

Location D, T. 1 N., R. 100 W.

	Ft. in.		Ft. in.
Shale, drab; contains sandy layers.....	40 0	Shale, with a few streaks of rich dark-brown shale.....	5 0
Shale, dark brown, rich.....	6	Shale, drab.....	30 0
Sandstone.....	6 0	Sandstone, thin bedded.....	2 0
Shale, dark brown, rich.....	1 0	Shale and thin sandstone; contains beds as thick as 2 feet which probably will yield some oil.....	45 0
Sandstone, thin bedded.....	5 0	Shale, thin bedded, lean.....	10 0
Shale, drab.....	20 0	Shale, drab, slightly sandy.....	15 0
Sandstone, thin bedded.....	3 0	Shale, thin bedded, lean.....	2 0
Shale, thin bedded, lean.....	15 0	Shale.....	30 0
Sandstone; contains much crystalline quartz; weathers like an oolite.....	4	Shale, thin bedded, slightly carbonaceous; in places contains thin sandy beds.....	25 0
Shale, drab, with sandy layers.....	30 0	Covered.....	65 0
Shale, dark brown, rich.....	3 0		399 4
Shale, drab.....	35 0		
Shale, lean.....	6		
Shale, sandy.....	4 0		
Shale; about 30 per cent rich shale in thin layers.....	4 0		
Shale, drab.....	3 0		

Location E, T. 1 N., Rs. 99 and 100 W.

	Ft. in.		Ft. in.
Sandstone, yellow, slightly friable; contains concretions of pyrite.....	15 0	Shale; estimated 15 per cent rich oil shale.....	20 0
bedded.....	20 0	Shale, gray on outcrop; top sandy, in beds 2 inches thick.....	20 0
Shale; upper part slightly sandy; contains some mica; lower part not well exposed.....	120 0	Shale, thin bedded; probably 15 per cent rich oil shale.....	10 0
Shale, dark gray to brown; contains a few beds of bituminous shale about half an inch thick.....	65 0	Shale, thin bedded, papery; estimated 75 per cent rich oil shale.....	7 0
Shale, gray, calcareous, in beds about 2 inches thick.....	8 0	Shale, sandy; contains few carbonaceous layers.....	5 0
Shale, gray to brown, slightly bituminous.....	20 0	Shale, thin bedded, estimated 50 per cent rich oil shale.....	1 6
Shale, dark brown, rich.....	3	Shale; contains little rich bituminous shale, but the whole is brown on fresh surface and probably will yield oil.....	1 0
Shale, thin bedded, gray on weathered outcrop but contains thin beds of brown and black rich bituminous shale; estimated that 10 per cent of the rock will yield oil.....	18 0	Shale, sandy, thin bedded.....	4 0
Shale, dark brown, thin bedded, 75 per cent rich and 25 per cent lean.....	1 0	Shale, dark brown, rich.....	1
		Shale, thin bedded, lean.....	6
		Shale, thin bedded, dark brown, rich.....	2 0
		Shale, sandy.....	2 0

Sections in northwestern Colorado—Continued.

Location E, T. 1 N., R. 99 and 100 W.—Continued.

	Ft.	in.		Ft.	in.
Shale, for the most part thin bedded, gray on weathered outcrop; probably 20 per cent of the whole is shale which will yield oil.....	13	0	Shale, thin bedded (estimated yield, 15 gallons).....	1	2
Shale, dark brown, massive; resists weathering; rich.....	2	0	Shale, drab.....	7	0
Shale, massive (estimated yield, 20 gallons).....	4	0	Sandstone, shaly.....	2	0
Shale, light gray, slightly sandy and bituminous.....	46	0	Shale, dark brown (estimated yield, 25 gallons).....	2	6
Shale, dark brown, rich.....	1		Shale, friable, yellow, lenticular.....	1	0
Shale, thin bedded, lean.....	18	0	Shale, drab.....	3	0
Shale (estimated yield, 20 gallons).....	6		Shale, very thin bedded (probable yield, less than 15 gallons).....	2	0
Shale, gray on weathered surface, thin bedded, lean.....	43	0	Shale, sandy.....	3	0
Sandstone, with numerous dark specks..	2		Shale, thin bedded, with a few bituminous layers.....	10	0
Shale, sandy.....	7	0	Shale, dark brown, rich, thin bedded (estimated yield, 35 gallons).....	3	0
Shale, dark brown; about 67 per cent rich and 33 per cent lean.....	1	0	Sandstone, contains quartz grains cemented with iron oxide.....	4	4
Shale, drab.....	1	0	Shale, thin bedded.....	4	4
Shale, dark brown; appears to be very rich (sample 13; 33.6 gallons).....	5	0	Shale, drab; contains sandy beds.....	5	0
Shale, about 50 per cent oil shale.....	2	0	Shale, gray, sandy.....	10	0
Shale, sandy.....	33	0	Shale, thin bedded, with some rich oil shale (estimated yield, 30 gallons).....	5	0
Shale, dark brown, rich.....	1	3	Shale, sandy.....	8	0
Shale.....	2	6	Shale, thin bedded; will yield some oil..	2	6
Shale, thin bedded, slightly carbonaceous, but will probably yield some oil.	6		Shale, sandy.....	7	0
Shale, gray, thin bedded.....	15	0	Shale, thin bedded, lean.....	5	0
Shale, dark brown, rich.....	6		Shale, drab; some layers 1 foot thick; will yield oil.....	10	0
Shale.....	8		Shale, dark brown, rich.....	4	4
Shale, dark brown, rich.....	6		Shale, thin bedded.....	4	0
Shale, thin bedded.....	4	0	Shale, brown (estimated yield, 25 gallons).....	3	0
Shale, dark brown, rich.....	2		Shale, about 50 per cent bituminous.....	2	0
Shale, thin bedded; contains possibly about 10 per cent rich shale.....	8	0	Shale, thin bedded, bituminous.....	7	0
Shale, dark brown, rich.....	1	0	Shale, thin bedded; contains rich bituminous layers; also sandstone lenses and lean shale.....	15	0
Shale.....	6		Sandstone, thin bedded.....	5	0
Sandstone, fine grained, massive.....	4		Shale, thin bedded (estimated yield, 15 gallons).....	3	0
Shale.....	8	0	Sandstone, light-colored.....	2	
Shale, dark brown, rich.....	2		Shale, dark brown; part rich and part lean.....	1	0
Shale, gray, thin bedded.....	7	0	Interval largely covered, but probably shale.....	40	0
Sandstone, shaly.....	2	0		874	9
Shale, sandy.....	7	0			
Shale, dark brown, rich.....	8				
Shale; contains some sandy beds.....	40	0			
Sandstone, yellow, shaly.....	15	0			
Shale and sandstone in about equal quantities.....	50	0			
Shale, dark brown, rich.....	6				
Sandstone, shaly.....	8				
Shale, dark brown, rich, with some sandstone lenses.....	1	0			
Sandstone, shaly.....	8	0			
Shale, very thin bedded (estimated yield, 25 gallons).....	1	6			
Shale, 25 per cent rich.....	1	0			
Shale, dark brown, interbedded with papery shale.....	6				
Shale, drab.....	3	0			
Shale, lean.....	3				
Shale, brown, thin bedded.....	6	0			

Between the last bed mentioned above and the base of the Green River formation there is a distance of about 300 feet in which the rocks are largely concealed by surface material. It is probable, however, that there is considerable oil shale in this interval, but that it has been burned so as to lose its ordinary characteristics. The burning is indicated by loose fragments of red burned rock on the surface, by slaglike masses of fused material, and by black burnt-out shale exposed near the base of the formation.

Sections in northwestern Colorado—Continued.

Location F, T. 2 N., R. 98 W.

	Ft. in.		Ft. in.
Sandstone (about 75 per cent) and slightly bituminous shale.....	150 0	Sandstone, weathers rusty tan.....	9 0
Shale, gray, sandy; some layers brown on fresh surfaces.....	45 0	Shale (80 per cent) and sandstone; some beds of shale 1 foot thick may yield as much as 15 gallons of oil to the ton....	40 0
Shale; about 20 per cent rich bituminous shale (samples 18, 19, 22, 23, and 24; 6.25 to 22.88 gallons)....	5 0	Shale (estimated yield, less than 10 gallons).....	1 0
Shale, thin bedded, slightly bituminous, and sandstone.....	150 0	Oolite.....	4
Sandstone, minutely cross-bedded, massive.....	1 0	Shale, slightly bituminous.....	$\frac{1}{2}$
Shale, drab; contains a few thin beds of sandstone.....	70 0	Oolite.....	2
Sandstone, massive; contains a few thin layers of conglomerate.....	2 4	Sandstone, thin bedded.....	5 0
Shale, in part slightly bituminous, with a few thin beds of sandstone.....	90 0	Oolite.....	2
Sandstone, in part chertlike.....	6	Shale, slightly bituminous.....	$\frac{1}{2}$
Shale, thin bedded.....	28 0	Oolite.....	3
Shale, dark brown, rich, and thin-bedded lean shale (estimated yield, 25 gallons).....	5 0	Sandstone, thin bedded, with some bituminous shale.....	58 0
Shale, sandy, lenticular.....	3 0	Shale, brown, lean, interbedded with thin sandstone.....	50 0
Shale, thin bedded (estimated yield, 15 gallons).....	4 0	Shale, brown to black, thin bedded, slightly bituminous.....	50 0
Sandstone.....	6	Shale, brown, very thin bedded; weathers curly (estimated yield, 15 gallons)....	1 0
Shale, dark brown, rich (sample 21; 26.8 gallons).....	11	Sandstone, shaly.....	15 0
Sandstone, cherty.....	2	Shale, brown, thin bedded; weathers curly (estimated yield, 15 gallons)....	1 0
Shale, dark brown, rich (sample 21; 26.8 gallons).....	3 7	Sandstone, shaly.....	8 0
Sandstone and shale.....	1 0	Shale, drab to gray, interbedded with thin beds of sandstone.....	90 0
Conglomerate with pebbles half an inch in diameter.....	2	Shale, brown to black, thin bedded (estimated yield, less than 15 gallons)....	25 0
Sandstone and shale, with layers of rich oil shale 1 inch thick.....	8 0	Shale, drab.....	10 0
Shale and some sandstone.....	8 0	Shale, brown on fresh surface, thin bedded, slightly bituminous.....	8
Sandstone.....	1 0	Shale, tan-colored; weathers white; many of the joint planes, which are at right angles to the bedding, are filled with a siliceous deposit.....	2 0
Shale, gray, thin bedded.....	34 0	Shale, gray; weathers almost white; upper part thin bedded; some of the shale is slightly carbonaceous.....	20 0
Sandstone, slightly conglomeratic and oolitic.....	8	Shale, drab and tan-colored.....	100 0
Shale, thin bedded (estimated yield, 25 gallons).....	5 0	Sandstone, light gray, fine grained, calcareous, ripple marked, lenticular.....	8 0
Shale, dark brown (sample 20; 12.6 gallons).....	3 0	Shale, drab and tan-colored.....	200 0
Sandstone, irregular in thickness, weathering light yellow.....	9	Sandstone, ripple marked, lenticular....	1 0
Shale, dark brown; weathers to papery shale (sample 14; 13.3 gallons).....	5	Shale, sandy.....	15 0
Sandstone, shaly.....	8	Sandstone, tan-colored, thin bedded....	1 0
Shale, light brownish drab; weathers to sheets one-eighth to three-eighths inch thick (sample 15; 3 gallons).....	1 2	Shale, drab.....	28 0
Sandstone, coarse, yellow.....	2	Shale, tan-colored.....	50 0
Shale, light brown..... (sample 16; 1.9 gallons).....	1 4	Oolite.....	6
Shale, dark brown, fairly rich, weathers papery.....	8	Shale, tan-colored.....	20 0
Shale, hard, dark brown; weathers to blue resistant ledges; this contains lenses of rock which weather yellow and resemble sandstone (sample 17; 21 gallons).....	6	Sandstone, thin bedded.....	6
		Shale, drab, thin bedded.....	40 0
		Sandstone, tan-colored, ripple marked, thin bedded.....	1 0
		Shale, with a few sandstone beds, tan colored; Wasatch formation.....	200 0
			1,677 $\frac{1}{2}$

Sections in northwestern Colorado—Continued.

Location G, T. 2 N., R. 97 W.

	Ft.	in.		Ft.	in.
Top of hill.			Shale, 10 per cent dark brown, rich and 90 per cent lean.....	2	0
Sandstone, massive, tan-colored, slightly friable, fairly coarse grained, weathers into nodular forms.....	5	0	Shale, thin bedded (possible yield, 15 gallons).....	10	0
Shale, sandy.....	300±		Shale, carbonaceous.....	3	0
Shale, dark brown, rich.....		½	Covered, probably mostly shale.....	100	0
Shale, sandy.....	30	0	Shale, curly; contains lenses of bituminous sandstone (samples 25 and 26, lower 8 feet of this bed; 4.78 and 3.85 gallons).....	15	0
Shale, dark brown (probable yield, 10 gallons).....	1	0	Shale, carbonaceous and sandy.....	2	0
Shale, drab, thin bedded.....	50	0	Sandstone.....	4	
Shale (estimated yield, 20 gallons).....	3	0	Shale, thin-bedded, carbonaceous; will probably yield a small quantity of oil.....	3	0
Shale, thin bedded, sandy.....	25	0	Interval, probably mostly lean shale but with a few thin beds which are rich in oil.....	60	0
Shale, dark brown, rich.....	1	0	Shale, thin bedded (estimated yield, 15 gallons).....	3	0
Shale, sandy.....	45	0	Sandstone.....	½	
Sandstone.....	3	0	Shale, thin bedded, black on fresh surface (estimated yield, 25 gallons).....	8	
Shale.....	5	0	Interval, covered, probably shale.....	6	0
Shale, dark brown, rich.....		½	Shale, dark gray to black, thin bedded (estimated yield, 25 gallons).....	3	0
Shale, sandy.....	100	0	Interval, mostly covered but probably sandy shale.....	20	0
Shale (estimated yield, 25 gallons).....	3	0	Oolite.....	10	
Shale, drab, with some sandy beds, lean.	60	0	Shale, thin bedded, brown on fresh surface, with sandstone beds as thick as 1 foot near the base (top includes beds estimated to yield less than 15 gallons).....	15	0
Shale, generally lean, but with some rich layers.....	1	0	Shale, thin bedded, brown on fresh surface; contains lenses of sandstone....	4	0
Shale (90 per cent) and sandstone (20 per cent).....	20	0	Interval, covered but probably shale....	15	0
Shale, thin bedded, containing thin layers of rich shale (probable yield of the whole, 15 gallons).....	5	0	Sandstone and sandy shale; the sandstone, especially in the upper part, is oolitic.....	13	0
Shale, drab, with some sandy layers....	20	0	Sandstone, mostly friable; contains beds which weather rusty.....	15	0
Shale, sandy.....	10	0	Shale.....	3	0
Shale, dark brown, with some lean beds (estimated yield of the whole, 25 gallons).....	2	0	Sandstone and oolite.....	3	0
Sandstone, shaly.....	1	0	Sandstone, friable.....	2	0
Shale, dark brown (estimated yield, 20 gallons).....	2	0	Shale, upper part sandy, lower part slightly carbonaceous in places.....	15	0
Shale, lean, oolite, and sandstone, intimately interbedded; oolite and sandstone lenticular.....	3	0	Oolite and sandy shale.....	3	0
Sandstone, shaly.....	3	0	Sandstone, shaly.....	8	0
Shale, drab.....	4	0	Sandstone, with oolitic phases.....	3	0
Sandstone.....	7	0	Sandstone, shaly, friable.....	3	0
Sandstone, shaly.....	10	0	Oolite.....	17	0
Shale, with some thin beds of sandstone; part of the shale is carbonaceous; other parts will probably yield a little oil....	40	0	Sandstone, friable.....	10	0
Interval, mostly covered but probably shale.....	50	0	Oolite.....	20	0
Shale, thin bedded (estimated yield, 15 gallons).....	2	0	Sandstone, shaly.....	15	0
Shale, carbonaceous, containing beds as thick as 6 inches which will yield oil..	20	0	Shale and sandstone, folded and faulted to such an extent that detailed measurements are not possible. The folding and faulting are believed to be confined to this member. Some of the shale will probably yield oil.....	100	0
Shale, sandy.....	15	0	Sandstone, tan-colored, slightly cross-bedded; contains oolitic layers near the top.....	17	0
Shale (estimated yield, 25 gallons).....	5	0			
Shale (estimated yield, 20 gallons).....	2	0			
Shale, thin bedded, mostly carbonaceous; some parts are flexible and probably will yield oil; benches as thick as 2 feet are estimated to yield 25 gallons.	30	0			
Shale, sandy, in places carbonaceous....	25	0			
Shale, for the most part drab and thin bedded; contains beds as thick as 1 foot which will probably yield 20 gallons.....	30	0			

*Sections in northwestern Colorado—Continued.***Location G, T. 2 N., R. 97 W.—Continued.**

	Ft. in.		Ft. in.
Sandstone, friable; contains a few thin lenses of oolite near the base.....	15 0	Oolite, containing numerous gastropods at the base.....	8 0
Sandstone, with lenses of oolite averaging about 2 inches long.....	1 0	Sandstone, shaly at the base, gray on unweathered surface.....	3 0
Sandstone, shaly; cut by normal faults having throws of 6 to 8 feet; fault planes dip about 50° S.; ripple marks were noted in the highest and lowest layers of the bed.....	3 0	Shale, slightly gray, sandy.....	4 0
Interval, mostly covered, probably sandy shale.....	40 0	Sandstone, with numerous gastropods..	1 0
Sandstone; contains oolitic phases.....	5 0	Sandstone, massive, slightly cross-bedded, fairly well rounded grains of quartz.....	4 0
Sandstone, shaly.....	1 0	Sandstone, calcareous, contains gastropod remains.....	6
Sandstone, oolitic.....	5 0	Sandstone, massive, slightly cross-bedded.....	15 0
Sandstone, shaly.....	3 0	Sandstone; weathers buff; resistant, in layers 1 inch to 6 inches.....	1 6
Sandstone, minutely cross-bedded; top oolitic.....	5 0	Shale, sandy, and friable sandstone; the sandstone predominates but does not form ledges. This is supposed to be typical Wasatch.	
Sandstone, shaly.....	1 0		1,605 11½
Oolite.....	15 0		
Sandstone, oolitic.....	2 0		
Shale, sandy, but contains carbonaceous beds, also sandstone layers as thick as 2 inches.....	25 0		

Section near location H, from gas well to mouth of Piceance Creek, T. 1 N., R. 97 W.

	Ft. in.		Ft. in.
Sandstone, coarse, yellowish brown, friable, cross-bedded.....	109 0	Sandstone, clayey.....	5 0
Shale, light gray.....	10 0	Shale, hard, brown, lean.....	3 0
Sandstone, tan-colored, friable.....	20 0	Sandstone, clayey, shaly.....	17 0
Sandstone, brown, friable.....	160 0	Shale, sandy (80 per cent), and hard, rich shale (20 per cent).....	2 6
Shale, light gray, sandy (sample 42; 0.31 gallon).....	45 0	Shale, hard, brown (sample 38; 25.2 gallons).....	5 11
Shale, gray, thin bedded.....	12 0	Shale, slightly sandy.....	10 0
Shale, hard, brown, rich, lenticular.....	1 0	Sandstone, calcareous.....	3 0
Shale, gray.....	73 0	Shale, partly rich and partly curly.....	3 0
Sandstone, yellowish brown at base, contains vegetable remains.....	55 0	Shale, top sandy, tan-colored.....	80 0
Shale, with few lenses of sandstone, much distorted.....	40 0	Shale, hard, brown, rich (90 per cent) and lean shale (10 per cent).....	2 0
Shale, sandy, very lean.....	5 0	Shale, thin bedded, carbonaceous, sandy.....	3 0
Shale, sandy at base.....	60 0	Shale, curly, lean (75 per cent), and hard, rich shale (25 per cent).....	3 4
Shale, sandy at top.....	24 0	Shale, sandy.....	5 0
Shale, hard, brown, rich.....	3	Shale, curly, lean.....	2 0
Shale, sandy.....	25 0	Shale, drab.....	6
Shale, sandy, thin bedded.....	2 6	Sandstone, irregularly bedded.....	2
Shale, lean (90 per cent) and hard, rich shale (10 per cent).....	1 6	Shale, thin bedded, lean.....	10 0
Shale, sandy, thin bedded, gray.....	3 0	Shale, thin bedded, lean (90 per cent), and hard, rich shale (10 per cent).....	6
Sandstone, massive, yellowish brown, coarse grained.....	17 0	Shale, thin bedded, sandy.....	5 0
Sandstone, yellowish, thin bedded.....	12 0	Shale, thin bedded (90 per cent), and hard, rich shale (10 per cent).....	1 0
Shale and thin beds of rich, hard shale..	32 0	Shale, slightly curly, lean.....	5 0
Shale, sandy, thin bedded.....	17 0	Sandstone, clayey.....	1 0
Shale, hard, rich, and thin-bedded shale.....	3 0	Shale, thin bedded at base, sandy at top.....	25 0
Shale, sandy.....	10 0	Shale, hard, rich.....	6
Shale, hard, brown, rich.....	1	Shale, sandy.....	2 0
Shale, sandy, thin bedded.....	30 0	Sandstone, calcareous.....	5 0
Shale, for the most part barren but including beds as thick as 1 foot which will yield considerable oil.....	132 0	Shale, thin bedded, curly.....	1 0
		Shale, hard, brown, variable thickness (sample 37; 23.25 gallons)....	5 8½
		Shale, thin bedded.....	20 0

Sections in northwestern Colorado—Continued.

Section near location H, from gas well to mouth of Piceance Creek, T. 1 N., R. 27 W.—Continued.

	Ft.	in.		Ft.	in.
Shale, curly, and hard, rich shales.....		10	Shale, curly, papery; will yield oil.....	40	0
Shale, brown, thin bedded, lean.....	3	0	Shale, dark brown, thin bedded.....		3 4
Shale, sandy, thin bedded.....	15	0	Shale, sandy.....		1 0
Shale, thin bedded, curly.....	1	0	Shale, brown, curly, with lenses of sandstone.....		5 0
Shale, sandy.....		5	Sandstone, lenticular.....		2
Shale, thin bedded, slightly curly.....	1	0	Shale, thin bedded.....	31; 15.5	1 2
Shale, hard, brown, rich.....	2	0	Shale, light brown, lean.....		8
Shale, brown, lean.....		10	Shale, very dark brown, curly, thin bedded.....		8
Shale, thin bedded, slightly carbonaceous.....	10	0	Shale, thin bedded brown.....		8
Shale, hard, rich.....		5	Shale, curly.....		4 4
Shale, black, carbonaceous, lean.....	2	0	Shale, curly papery; will yield oil.....	20	0
Shale, thin bedded, drab.....	18	0	Covered, mostly shale.....	30	0
Shale, hard, rich (50 per cent), and lean shale (50 per cent).....	2	0	Shale, curly, papery, will yield oil.....	3	0
Shale, slightly curly (95 per cent), and rich shale (5 per cent).....	1	0	Covered, probably mostly shale.....	15	0
Shale, sandy.....	100	0	Shale, dark brown, rich.....		1
Shale, hard, rich, and lean shale (estimated yield, 30 gallons).....	3	0	Shale, much of it papery, curly; will yield a small amount of oil.....	154	0
Shale, thin bedded, lean.....	5	0	Shale, curly, papery, fairly rich (samples 27, 28, 29, and 30; 8.4 to 12.5 gallons)...		15 0
Shale, massive, rich, weathers bluish.....	5	0	Shale, much of it curly and will yield oil.....	67	0
Shale, thin bedded, lean (90 per cent), and rich shale (10 per cent).....	52	0	Shale, curly, papery; will yield oil.....	8	0
Shale, dark brown, rich, and lean shale (50 per cent each).....	16	0	Shale and clay, tan.....	48	0
Shale, hard, dark brown, rich.....	5	0	Oolite.....	1	0
Shale, drab.....	2	0	Shale, sandy at base.....	40	0
Shale, thin bedded, lean.....	3	0	Oolite.....	3	0
Shale, weathers blue; massive, rich (samples 32, 33, 34, 35, and 36; 14.7 to 40.6 gallons).....	5	0	Sandstone.....	42	0
Shale, thin bedded, lean.....	31	0	Sandstone, ripple marked at top, with lenses of oolite.....	22	0
Shale, hard, dark brown, rich.....	3	0	Shale, sandy.....	5	0
Shale, hard, black, rich.....	1	0	Oolite, massive; weathers brown.....	3	0
Shale, thin bedded, lean.....	28	0	Sandstone.....	8	0
Shale, hard, dark brown; estimated yield, 15 gallons.....	1	0	Sandstone, oolitic at base, thin bedded at top.....	7	0
Shale, light gray.....	2	0	Oolite.....	2	0
Shale, curly; will yield oil.....	1	6	Sandstone.....	41	0
Shale, dark brown, hard, rich.....	3		Sandstone, brown, fossiliferous (gastropods).....	2	0
Shale, sandy, carbonaceous.....	3	4	Sandstone, massive, irregular base, ripple marked on top.....	5	0
Shale, curly, papery, and small lenses of solid hydrocarbons.....	2	0	Covered, but probably tan-colored shale.....	83	0
Shale, dark brown, hard, rich.....		4	Sandstone, resistant and cross-bedded at top, friable near base.....	27	0
Shale, drab.....	37	0	Sandstone, light gray to white, coarse.....	3	0
Shale, partly papery, curly, with a few thin one-half inch beds of hard, dark-brown, rich shale.....	35	0	Sandstone, clay, and varicolored lenticular shale.....	200	0
				2,496	6½

Location I, north of White River, T. 1 N., R. 26 W.

	Ft.	in.		Ft.	in.
Sandstone, ripple marked.....	25	0	Shale, lean (25 per cent), and rich shale (75 per cent).....	1	0
Sandstone and shale.....	189	0	Shale, sandy.....	4	0
Sandstone, conglomeratic, friable, yellow.....	15	0	Shale, dark brown, massive, rich.....	1	0
Shale, yellow.....	58	0	Sandstone, friable.....		6
Shale, drab.....	1	0	Shale, thin bedded, and lean brown shale.....		4 0
Shale, brown, lean.....	1	0	Sandstone, oolitic, tan-colored.....	1	0
Shale, drab, with thin beds of rich shale.....	2	0	Shale, gray, thin bedded.....	15	0
Shale, thin bedded, curly.....	1	0	Sandstone, oolitic and conglomeratic.....	3	0
Shale, drab.....	1	0			

*Sections in northwestern Colorado—Continued.***Location I, north of White River, T. 1 N., R. 96 W.—Continued.**

	Ft.	in.		Ft.	in.
Shale, gray, thin bedded.....	35	0	Sandstone, oolitic and collite.....	10	0
Shale and sandstone, lean.....	77	0	Shale and thin beds of sandstone.....	85	0
Sandstone, friable.....	4	0	Shale, brown, curly.....	5	0
Shale, sandy.....	2	0	Sandstone, friable, lenticular.....	10	0
Shale, curly (estimated yield, not more than 10 gallons).....	5	0	Shale, sandy, drab.....	47	0
Interval.....	24	0	Shale, thin bedded.....	3	0
Sandstone, oolitic, ripple marked.....	3	0	Shale, sandy, drab.....	75	0
Shale and sandstone, lenticular.....	167	0			
				874	6

Location J, T. 1 N., R. 96 W.

	Ft.	in.		Ft.	in.
Shale, gray; probably will yield little or no oil.....	200		Sandstone, tan-colored.....		4
Shale, containing a few thin beds of rich black shale.....	20	0	Shale; probably will yield a small amount of oil.....		10
Shale; contains a large number of rich layers interbedded with sandy shale..	20	0	Shale, gray.....	6	0
Shale, thin bedded; contains a large number of thin beds of rich shale; the whole slightly richer than the unit next above.....	15	0	Shale, hard, dark brown, rich.....	2	0
Shale, hard, dark brown, rich.....	6		Shale, papery, lean.....	3	0
Shale; contains a few thin beds of rich shale.....	8	0	Shale, sandy.....	5	
Shale, hard, dark brown, rich.....	2		Shale, dark brown, rich.....	1	1
Shale, thin bedded, slightly sandy.....	2	0	Shale, lean.....	7	
Shale, hard, dark brown, rich (sample 41; 13.7 gallons).....	1	4	Shale, rich.....	8	
Shale, lean.....	2	0	Shale, gray, slightly sandy.....	10	0
Shale, hard, brown, massive (sample 40; 12.5 gallons).....	3	8	Shale, hard, dark brown, rich.....	6	
Shale, interbedded with layers of rich shale; the whole probably lean.....	6	0	Shale, lean.....	6	0
Shale, thin bedded, slightly sandy.....	15	0	Shale, very lean.....	1	0
Shale, hard, dark brown, rich.....	4		Shale, sandy.....	5	0
Shale, thin bedded.....	5	0	Shale, dark brown, rich.....	1	
Shale, hard, dark brown, rich.....	10		Shale, lean.....	1	6
Shale, sandy.....	5	0	Shale, hard, dark brown, rich.....	3	
Shale, hard, dark brown, rich.....	1	0	Shale, lean.....	10	
Sandstone.....	8		Shale, dark gray, thin bedded, lean.....	6	
Shale, hard, dark brown, rich with some lean layers.....	3	0	Shale, gray, slightly sandy.....	5	0
Shale, thin bedded, slightly sandy.....	50	0	Shale, brown to black, thin bedded, rich.....	3	0
Shale, hard, dark brown, rich.....	8		Shale, brown to black, thin bedded, probably lean.....	2	0
Shale, thin bedded, slightly sandy; containing caverns in places filled with solid hydrocarbon.....	5	0	Shale, sandy, thin bedded.....	3	6
Shale, sandy.....	7	0	Shale, dark brown to black, thin bedded, lean.....	2	10
Shale, lean.....	1	0	Shale, dark brown to black, thin bedded to almost papery, lean.....	1	6
Shale, hard, dark brown, rich.....	1	0	Shale, hard, dark brown, rich.....	2	
Shale, thin bedded, slightly sandy.....	5	0	Shale, drab, thin bedded, sandy.....	5	0
Shale, hard, dark brown, rich.....	1	0	Sandstone, massive, showing slight ripple marks.....	3	0
Shale, lean, slightly sandy.....	2	0	Shale, sandy.....	8	0
Shale, sandy, thin bedded.....	11	0	Sandstone, massive, resistant.....	2	0
Shale, sandy; contains a few thin layers of rich shale.....	5	0	Shale, gray, thin bedded.....	3	0
Shale, gray, slightly sandy.....	4	0	Sandstone.....	4	
Shale, hard, dark brown, rich, with lean shale interbedded.....	1	10	Shale, gray, thin bedded.....	45	0
Shale, gray, slightly sandy.....	8	0	Sandstone, massive, cross-bedded.....	15	0
Shale, lean.....	6		Shale, gray, thin bedded.....	5	0
Shale, sandy.....	3	4	Shale, dark gray to black, probably lean.....	1	0
			Shale, gray, thin bedded, with thin beds of sandstone.....	25	0
			Shale, hard, dark brown, rich.....	3	
			Shale, weathers gray, lean.....	1	0
			Shale, gray, thin bedded.....	12	0
			Shale, thin bedded, dark brown to black on fresh surface (sample 39; 13.7 gallons).....	3	0
			Shale, hard, brown, probably rich.....	6	

*Sections in northwestern Colorado—Continued.***Location J, T. 1 N., R. 96 W.—Continued.**

	Ft.	in.		Ft.	in.
Shale, thin bedded, lean.....	8		4 inches and as thick as one-quarter inch.....	3	0
Shale, hard, dark brown, rich.....	3		Sandstone, tan-colored, massive, slightly friable, minutely cross bedded.....	35	0
Sandstone, with numerous fragments of vegetable remains.....	2	0	Shale, drab, sandy.....	55	0
Shale, gray, sandy, with thin beds of lean shale.....	10	0	Sandstone.....	1	0
Sandstone, coarse grained, conglomeratic, containing flat pebbles of shale.....	1	0	Sandstone and shale, fossiliferous.....	30	0
Shale and sandstone; much of the surface covered.....	45	0	Sandstone, tan-colored on weathered surface, minutely cross-bedded.....	2	0
Sandstone, conglomeratic, tan-colored; contains flat pebbles of shale as long as			Shale, sandy; one fossil leaf was found in this member.....	5	0
				1,666	104

Location K, on north side of Fourteenmile Creek, T. 3 S., R. 95 W.

	Ft.	in.		Ft.	in.
Sandstone, brown, massive.....	50	0	Shale, thin bedded, lean.....	11	0
Shale, light brown.....	75	0	Sandstone, coarse grained, irregular bedded.....	6	
Shale, thin bedded, light brown, lean (sample 44; 6.2 gallons).....	64	0	Shale, bluish gray.....	11	0
Sandstone, shaly.....	19	0	Sandstone, fine grained.....	8	
Shale, thin bedded; weathers light gray; probably as rich as the bed from which sample 43 was taken.....	40	0	Shale, bluish gray; contains vegetable remains.....	12	0
Sandstone, shaly.....	17	0	Sandstone, brown, shaly.....	10	0
Shale, thin bedded; weathers light gray; probably as rich as the bed from which sample 43 was taken.....	59	0	Shale, gray, with a few thin beds of rich shale.....	117	0
Shale, dark brown, but probably not rich.....	3		Sandstone, grayish brown.....	8	
Shale, thin bedded, very hard, black.....	1	5	Shale, drab, platy; contains stems of wood and pockets of solid hydrocarbon.....	65	0
Shale, brown, hard, probably lean.....	7		Sandstone, gray.....	4	0
Shale, very dark brown, hard.....	1	6	Shale, gray.....	17	0
Shale, dark brown, containing small lenses of sandstone.....	1	0	Sandstone, brown.....	1	0
Sandstone, irregular in thickness.....	2		Shale, gray.....	2	0
Shale, lean (80 per cent), and rich, brown shale (20 per cent).....	35	0	Sandstone, brown.....	1	0
Shale, light brown; weathers white; lean.....	7	0	Shale, gray, clayey.....	77	0
Interval, probably mostly shale.....	40	0	Sandstone, coarse, yellow.....	7	0
Shale, gray.....	110	0	Shale, drab; contains wood fragments.....	80	0
Shale, thin bedded; light colored.....	10	0	Sandstone, coarse, angular grains, yellow.....	2	0
Shale, dark drab, thin bedded.....	28	0	Shale, gray.....	5	0
Shale, very thin bedded, with thin layers of rich, dark-brown shale.....	1	0	Sandstone, brown, coarse.....	1	0
Shale, gray, lean; weathers to small plates.....	5	0	Shale, light drab.....	15	0
			Sandstone, coarse, yellowish brown.....	3	0
			Shale, light drab, very clayey.....	53	0
			Sandstone, yellowish brown, ripple marked.....	1	6
			Shale, drab, sandy, with three thin beds of brownish sandstone.....	32	0
			Sandstone, yellowish brown, upper part oolitic; contains rounded quartzite pebbles.....	19	0
			Top of Wasatch formation.....		
				1,113	

Location L, on Piceance Creek, T. 4 S., R. 94 W.

	Ft.	in.		Ft.	in.
Sandstone, brown, massive.....	150±		Shale, dark brown, hard; weathers gray; lean.....	40	0
Shale, sandy; weathers light gray.....	95	0	Shale, hard, dark brown (estimated yield, 30 gallons).....	1	0
Shale, dark brown, hard; weathers gray; lean.....	112	0	Shale, dark brown; weathers gray; lean.....	168	0
Shale, hard, dark brown, rich.....	5		Shale, dark brown, rich, and thin-bedded shale.....	2	0
Shale, dark brown, hard; weathers gray (probable yield, less than 15 gallons).....	11	0	Shale, brown; weathers gray; with a few thin beds of hard, dark-brown, rich shale.....	38	0
Shale, hard, black; weathers bluish (estimated yield, 25 gallons).....	2	0			

*Sections in northwestern Colorado—Continued.***Location L, on Piceance Creek, T. 4 S., R. 94 W.—Continued.**

	Ft.	in.		Ft.	in.
Sandstone, shaly; weathers reddish brown.....	90	0	Sandstone, brown.....	10	0
Shale, drab.....	100	0	Shale, drab, somewhat sandy, interbedded with about 20 per cent of sandstone in beds 8 inches thick.....	65	0
Sandstone.....	4	0	Sandstone, brown.....	8	0
Shale.....	18	0	Shale, drab, sandy, with about 40 per cent of sandstone in beds 1 foot thick.....	45	0
Sandstone.....	3	0	Sandstone, gray.....	15	0
Shale, drab, slightly sandy.....	523	0	Sandstone in beds averaging 6 feet thick, interbedded with gray sandy shale (shale probably 50 per cent of the whole).....	200	0
Shale, bluish drab, with about 5 per cent of beds of sandstone 8 inches thick....	102	0	Sandstone, massive, brown.....	12	0
Shale, drab, slightly sandy, interbedded with layers of sandstone 1 foot thick....	120	0	Sandstone and gray shale, Wasatch.....	2,002	5
Sandstone, brown, coarse grained.....	8	0			
Shale, drab, slightly sandy, with about 8 per cent of sandstone in beds 4 inches thick.....	60	0			

Location M, on north side of Pole Gulch, T. 4 S., R. 94 W.

	Ft.	in.		Ft.	in.
Shale, light brown, weathers gray; contains a few thin beds of rich shale.....	75	0	Shale, brown, probably not quite as rich as the bed from which sample 46 was taken.....	4	6
Shale, black, massive; weathers dark blue; rich.....	1	0	Shale, light brown; will yield a small quantity of oil.....	5	0
Shale, light brown; weathers gray; contains several thin beds of sandstone, also thin beds of rich shale.....	17	0	Shale, brown, weathers thin bedded, curly (estimated yield, 15 gallons)....	2	0
Shale, dark brown, rich.....	8		Shale, light brown, with beds of rich shale (probable yield less than 10 gallons)...	11	0
Shale, light brown, weathers gray; will yield a small quantity of oil.....	25	0	Shale, dark-brown, weathers blue.....	1	1
Shale, brown (sample 46; 12.5 gallons)....	5	2	Shale, very light brown; weathers yellowish gray; will yield very little oil.....	15+	
Shale, gray, lean.....	5	0		167	5

Location N, on the face of a cliff southwest of Cook's ranch, T. 4 S., R. 94 W.

	Ft.	in.		Ft.	in.
Top of cliff approximately 1,400 feet above the base of the Green River formation.			Shale, dark brown, rich.....	1	
Shale, thin bedded; weathers platy; lean.	15	0	Sandstone, irregularly bedded.....	2	
Shale, dark brown, rich; weathers bluish gray and thin bedded.....	6		Shale, dark brown, rich, containing much pyrite.....	2	
Shale, light brown; weathers yellow; probably will yield a small quantity of oil.....	3	0	Shale, gray and thin sandstone.....	10	0
Shale and thin sandstone bed.....	5	0	Shale, dark brown, rich; weathers bluish gray.....	1	
Shale, lean.....	3	6	Shale, lean.....	11	0
Shale, yellowish gray; will yield but little oil.....	5	0	Shale, hard, dark brown; weathers bluish gray; contains a large amount of pyrite.....	10	0
Shale, light brown; weathers to thin laminae (sample 49; 10.5 gallons).....	3	0	Shale, gray (may yield as much as 10 gallons).....	11	0
Shale, yellowish gray, probably very lean.	7		Shale, thin bedded (may yield as much as 15 gallons).....	8	
Shale, dark brown, rich.....	6		Shale, weathers white.....	16	0
Shale; weathers gray; probably will yield a small quantity of oil.....	7	0	Shale; weathers bluish (will not yield more than 10 gallons).....	10	
Shale, dark brown, rich (sample 48; 15.5 gallons).....	4	0	Shale, dark brown, rich; weathers blue; contains a large amount of pyrite.....	3	
Shale and thin-bedded sandstone; will probably yield a little oil.....	5	0	Shale and sandstone.....	6	0
Shale, brown, lean.....	2	0	Shale; weathers white.....	1	
Shale, light gray.....	6	0	Sandstone.....	3	
Shale, dark brown, rich; weathers bluish gray.....	5		Shale; weathers white; lean.....	1	6
Shale, lean (estimated yield, 10 gallons)...	2	0	Sandstone.....	3	
Shale, light brown, very lean.....	4	0	Shale; weathers white; will yield a little oil.....	1	8
Shale, dark brown, rich.....	1		Shale; weathers bluish, thin bedded (sample 47, 7 gallons).....	2	0
Shale.....	3		Shale; will yield a little oil.....	2	6
			Talus slope concealing the lower rocks.....		

Sections in northwestern Colorado—Continued.

Location O, in Book Cliffs north of Morris station, T. 6 S., R. 94 W.

	Ft. in.		Ft. in.
Shale, brown, makes the upper part of the cliff; probably will yield considerable oil but could not be examined.....	210±	Shale (90 per cent) and sandstone (10 per cent); this member contains beds of sandstone as thick as 8 feet; shale is in places slightly carbonaceous.....	100 0
Shale, weathers thin bedded; black to bluish gray (sample 50; 40.6 gallons).....	10 0	Sandstone, light tan-colored to gray, very persistent in thickness.....	5 0
Shale (probably will yield less than 15 gallons).....	25 0	Sandstone (25 per cent) in beds not over 8 inches thick, and drab shale (75 per cent).....	25 0
Shale, hard, black, rich.....	2 0	Oolite (50 per cent) and thin-bedded carbonaceous shale (50 per cent); contains fish scales.....	2 0
Sandstone (excluded from sample)..... (sample 51; 28 gallons)	2	Sandstone (10 per cent) and shale (90 per cent); some of the sandstone beds are as thick as 5 feet and are conglomeratic....	60 0
Shale, light brown, very hard.....	1 10	Shale, drab; contains a few thin beds of sandstone.....	60 0
Shale, black, hard; appears to be very rich....	5	Shale (90 per cent), in places thin bedded and slightly carbonaceous, and sandstone, in part ripple marked (10 per cent).....	70 0
Shale; weathers white; thin bedded, slightly carbonaceous; contains a few thin beds of rich shale, also sandstone lenses.....	40 0	Sandstone (50 per cent) and gray shale, in part clayey (50 per cent); sandstone at top is even bedded and appears persistent; that in the lower part is irregular in thickness.....	100 0
Shale, light yellow, thin bedded, sandy..	30 0	Shale, for the most part gray (75 per cent) and thin-bedded sandstone (25 per cent)	300 0
Sandstone, coarse grained.....	2 0	Sandstone and shale; sandstone beds are massive, tan-colored for the most part and cross-bedded; shale in the lower part of the member is yellow and is similar to Wasatch. At the base of the member is a bed of massive sandstone 10 feet thick with 15 feet of thin-bedded sandstone above. These beds are irregular in thickness and look like the typical Wasatch.....	750 0
Shale; weathers white; contains some sandy beds.....	40 0	Variegated clays and shales with sandstone lenses at irregular intervals.....	2,082 2
Shale, rich, dark brown.....	1		
Shale, slightly sandy, thin bedded.....	1 0		
Shale, rich, dark brown.....	3		
Shale, slightly sandy, gray.....	1 0		
Shale, dark brown, rich.....	8		
Shale, lean.....	6		
Shale, mostly gray, partly sandy, contains a few beds of curly shale; the whole is supposed to be very lean.....	75 0		
Shale, with some sandstone beds as thick as 2 feet.....	120 0		
Sandstone, tan-colored, coarse grained...	25 0		
Shale, dark brown, rich.....	3		
Sandstone (90 per cent) and shale (10 per cent); sandstone coarse grained, cross-bedded, and conglomeratic in lower part.....	25 0		

Location P, in upper part of Book Cliffs north of Rulison, Colo., T. 6 S., R. 95 W.

	Ft. in.		Ft. in.
Shale, massive, probably will yield considerable oil; forms at this locality impassable cliff.....	100±	Sandstone, shaly.....	10 0
Shale, light brown (sample 54; 11.2 gallons).....	15 0	Shale, probably fairly rich in oil....	35 0
Shale brown, probably richer than that of the bed above.....	100 0	Shale, thin bedded; weathers black; inclined to be curly (to be correlated with the bed from which sample 50 was taken; see above)...	6 0
Shale, dark brown (sample 55; 15.4 gallons).....	13 0	Shale; weathers yellowish; lean.....	25 0
Shale, probably as rich as that above	20 0	Shale, dark brown; weathers gray (sample 54; 20.7 gallons).....	8 0
		Talus slope.....	332 0

Sections in northeastern Utah.

Location Q, along Evacuation Creek between Temple switch and Dragon, Utah.

	Ft.	in.		Ft.	in.
Shale, thin bedded, lean to barren.....	40	0	Shale, sandy; weathers greenish gray; lean to barren.....	2	0
Shale, hard, dark (estimated yield, 20 gallons).....	1	0	Shale, hard (sample 59; 9 gallons).....	1	0
Shale, lean to barren, thin bedded; a few rich layers less than 1 inch thick (Diptera larvae).....	185	0	Sandstone, rough, coarse, containing asphalt; top and bottom surfaces irregular, with shale conforming to the irregularities.....	1	10
Sandstone.....	1	0	Shale.....	7	0
Shale, platy, lean to barren; two or three rich beds about 1 inch thick.....	36	0	Sandstone, persistent.....	8	
Shale, thin bedded, rich.....	1	0	Shale, lean, sandy, gray to reddish, with several thin layers of sandstone.....	13	8
Shale, lean.....	6	0	Shale, hard, rich..... (sample 74; 2 gallons).	2	0
Sandstone, persistent.....	5		Shale, soft..... (sample 74; 2 gallons).	2	0
Shale, lean, thin bedded.....	4	0	Shale, hard, rich..... (sample 74; 2 gallons).	1	9
Shale, hard, dark brown, rich.....	1	10	Sandstone.....	3	
Shale, hard, light brown, rich.....	2	1	Shale, hard.....	3	
Shale, hard, dark brown, rich..... (sample 68; 31 gallons).	6		Sandstone (not included in sample).....	1	1
Shale, sandy (not in sample).....	68; 31		Shale, hard.....	1	7
Shale, hard, dark brown, rich.....	2		Sandstone, persistent (not included in sample)..... (sample 73; 6 gallons).	2	
Shale, hard, light brown, rich.....	3		Shale, hard.....	11	
Shale, hard, dark brown, rich.....	10		Shale, clayey.....	5	
Shale, hard, dark brown, rich.....	8		Shale, hard, mostly lean, with thin beds of richer shale.....	1	6
Shale, dark, tough..... (sample 67, from richest part of upper bench; 90 gallons. Sample 65, from whole bed at surface; 32 gallons.)	1	4	Sandstone, persistent.....	3	
Shale, dark, platy.....	1	5	Shale, hard, rich.....	2	9
Shale, hard, dark, rich.....	2	1	Sandstone..... (sample 72; 7 gallons).	1	
Shale, soft, dark brown.....	3		Shale, hard, rich.....	2	6
Shale, hard, dark, rich.....	3		Sandstone.....	2	
Shale, soft, dark brown.....	3		Shale, hard, dark (sample 71; 7 gallons).....	7	0
Shale, hard, dark, rich..... (sample 66, from whole bed 1½ feet back from outcrop; 55 gallons.)	5		Sandstone, persistent.....	6	
Shale, thin bedded, platy..... (sample 66; 15 gallons.)	3	1	Shale, hard, rich to lean.....	3	3
Shale, rather lean and papery.....	4	2	Horizon of sandstone lenses, none of which came where sample was taken..... (sample 70; 14 gallons).	1	
Shale, hard, dark brown to black (sample 63; 32 gallons).....	4	3	Shale, hard, rich.....	2	6
Shale, hard, lean, some thin sandstone layers.....	3	10	Sandstone.....	1	
Shale, hard, rich (samples 58 and 62; 23 and 18 gallons, respectively).....	3	11	Shale, probably, lean. Sandstone, bearing gypsum (not included in sample).....	7	
Shale, minutely banded, some rich layers (sample 61; 10 gallons).....	6	7	Shale, hard, dark, rich; some gypsum near top..... (sample 69; 19 gallons).	1	10
Shale, lean to barren, with two bands of small dark sandstone lenses.....	4	0	Shale, with considerable gypsum.....	4	
Sandstone, hard, quartzitic, persistent.....	5		Shale, very dark brown, rich.....	5	
Shale, sandy, barren; thin beds of sandstone.....	3	1	Sandstone, brownish, shaly.....	23	0
Shale, brown and black, rich..... (sample 60; 12 gallons).	7		Shale, papery, lean.....	1	6
Shale, hard; weathers green.....			Shale, rich; weathers blue.....	6	
			Shale, sandy, and barren shaly sandstone.....	10	0
			Shale, rich, papery.....	6	
			Shale, sandy, barren.....	17	6
			Sandstone, brown, massive.....	11	

Sections in northeastern Utah—Continued.

Location Q, along Evacuation Creek between Temple switch and Dragon, Utah—Continued.

	Ft.	in.		Ft.	in.
Shale, lean to barren.....	2	6	Shale, drab.....	11	0
Sandstone, massive, ledge making.....	5	0	Sandstone, poorly cemented.....	4	6
Sandstone, brownish, shaly.....	50	0	Shale, drab to green.....	17	0
Shale, forming ledge, lean to rich..	4	6	Oolite, much distorted.....	2	8
Shale, papery, lean to barren.....	4	0	Shale, gray.....	1	0
Shale, hard, rich.....	3		Oolite, much distorted.....	8	6
Shale, sandy, lean to barren; two or three sandstone ledges less than 1 foot thick.....	43	0	Shale, sandy.....	19	0
Shale, papery; numerous thin blue rich bands.....	7	0	Oolite.....	3	0
Shale, barren, with several brownish sandstone layers 2 to 4 inches thick..	20	0	Sandstone, massive.....	7	0
Shale; weathers bluish; rich, ledge forming.....	1	0	Oolite.....	1	2
Shale; weathers bluish; barren.....	2	7	Sandstone, massive for the most part; some oolitic members near base.....	61	0
Sandstone, light brown.....	1	0	Shale, drab; upper surface very irregular.....	4	0
Shale; weathers bluish; barren.....	1	5	Sandstone, massive.....	8	0
Sandstone, light brown.....	4	0	Sandstone, shaly.....	18	0
Shale; weathers bluish; barren.....	1	6	Shale, gray, sandy.....	7	0
Sandstone, light brown.....	8		Sandstone, yellow, massive.....	5	6
Shale; weathers bluish; barren.....	1	3	Shale, gray, sandy.....	17	0
Sandstone, massive.....	2	6	Sandstone, massive.....	3	0
Sandstone, gray, shaly.....	3	0	Shale, drab.....	2	0
Sandstone, yellowish brown, not well cemented.....	48	0	Sandstone, massive.....	14	0
Shale, gray.....	35	0	Shale, drab to dark, sandy and concretionary.....	5	6
Sandstone.....	4	0	Shale, platy, gray and drab.....	11	0
Shale, gray.....	7	0	Oolite.....	6	
Sandstone.....	2	0	Sandstone, finely cross-bedded, poorly cemented.....	5	0
Shale, drab.....	13	0	Oolite.....	10	
Oolite.....	6	0	Sandstone, massive.....	2	0
Shale, drab.....	42	0	Shale, drab, sandy.....	3	10
Oolite.....	2	4	Sandstone, massive.....	1	6
Shale, gray.....	4	0	Shale, drab.....	3	3
Oolite.....	3	10	Sandstone, massive.....	3	0
Shale, gray.....	14	6	Shale, gray and drab.....	102	0
Sandstone, massive cross-bedded.....	14	0	Sandstone, minutely cross-bedded.....	8	
Shale, drab.....	6	0	Shale, gray and drab.....	97	0
Sandstone, massive.....	8	6	Oolitic sandstone, forming ledge; lower 4 inches conglomeratic and may well be considered basal member at Green River.....	1	4
Shale, gray and drab.....	28	0	Sandstone, yellow, poorly cemented.....	28	0
Sandstone, resistant.....	10		Shales, red and green, undoubtedly Wasatch.....	1,306	10½
Shale, drab.....	4	0			
Sandstone, massive.....	23	0			

Location R, north side of Saddle Post Canyon, sec. 22, T. 11 S., R. 25 E.

	Ft.	in.		Ft.	in.
Shale, hard, rich, weathers papery.....	2	11	Shale, lean; weathers white and platy..	2	4
Shale, rather soft, white on surface, platy.....			Shale, hard, rich.....	10	
Shale, hard, rich.....	1	7	Shale, lean.....	12	0
Shale, white, platy.....	10		Shale, hard, rich.....	4	
Shale, hard, rich.....	9		Shale, lean, platy.....	4	8
Shale, lean to rich; weathers papery.....	1	6	Sandstone, persistent, quartzitic (identical with 5-inch sandstone at location Q; see p. 183).....	5	
Shale, lean; weathers white and platy..	1	3			
Shale, rich; weathers papery.....	6½			30	8½

Sections in northeastern Utah—Continued.

Location S, sec. 24, T. 11 S., R. 25 E.

	Ft.	in.		Ft.	in.
Sandstone.....		8	Shale, lean.....	2	0
Shale, lean, sandy.....	20	0	Shale, rich.....	1	0
Shale, rich.....		8	Shale, rich, and papery shale.....	4	0
Shale, lean.....	6	0	Shale, medium rich.....	3	0
Shale, rich.....	1	6	Shale, rich, hard.....		2
Shale, lean to barren.....	6	6	Shale, lean.....	4	0
Sandstone.....		5	Shale, medium rich.....	9	0
Shale, lean.....	4	6	Shale, lean.....	4	0
Shale, rich.....		8	Sandstone, ferruginous.....		5
Shale, lean.....	4	0	Shale, lean to barren.....	4	6
Shale, rich.....		10	Shale, hard, rich.....		6
Shale, lean, papery.....	1	6	Shale, lean to barren.....	5	0
Shale, rich.....		3	Sandstone, coarse, asphaltic (same as 22-		
Shale, soft.....	(sample 78;	2	inch asphaltic sandstone at location Q;		
Shale, rich.....	48 gallons).	4	see p. 183).....	1	1
Shale, soft.....		1			
Shale, rich.....		8		91	9

Location T, on north side of Hells Hole Canyon, sec. 22, T. 10 S., R. 25 E.

	Ft.	in.		Ft.	in.
Shale, platy, sandy, lean to barren.....	13	0	Shale, hard.....	(sample 83;	1
Shale, mostly lean, with rich beds too thin to sample.....	11	0	Sandstone.....	8 gallons).	1
Shale, thin, platy.....	1	11	Shale, hard, rich.....		2
Shale, hard, rich.....	(sample 91;	3	Shale, hard, richest in upper 2 feet		
Shale, lean.....	29 gallons).	2	(sample 82; 20 gallons).....		6
Sandstone, persistent.....		5	Sandstone, asphaltic, variable in thickness (same as 22-inch asphaltic sandstone at location Q, see p. 183).....	1	4
Shale, lean, platy, containing one 6-inch bed of rich shale.....	6	5	Shale, hard, rich (sample 81; 24 gallons).....	1	11
Shale, hard, very rich.....	3	2	Sandstone.....		1
Shale, very sandy, lean.....		11	Shale, sandy, platy, lean to barren.....	28	0
Shale, hard, rich (sample 90; 45 gallons).....	4	8	Shale, rich.....		3
Shale, hard.....	(sample 89;	1	Shale, lean to barren, sandy.....	2	4
Shale, soft.....	17 gallons).	1	Shale, rich.....		2
Shale, hard, rich.....		1	Shale, lean to barren.....	2	6
Shale, lean to barren.....	1	9	Sandstone.....		1
Shale, rich (A).....	(sample 86;	1	Shale, gray, lean to barren.....	18	6
Shale, soft (B).....	of whole	1½	Shale, hard, rich.....		2
Shale, rich (A).....	bed, 37 gal-	3½	Shale, gray, lean to barren.....	2	10
Shale, soft (B).....	lons; sam-	3½	Shale, alternating		
Shale, rich (A).....	ple 87, of	½	hard and soft layers.....	(sample 80;	2
Shale, soft (B).....	parts of	1	Shale, soft.....	33 gallons).	1
Shale, rich (A).....	bed mark-	5	Shale, alternating		
Shale, soft (B).....	ed "A," 54	7	hard and soft layers.....		1
Sandstone (discarded).....	gallons;	1	Shale, lean.....	5	0
Shale, soft (B).....	sample 88,	6	Shale, rich.....		1
Shale, rich (A).....	of parts of	1	Shale, papery, or sandy and platy, lean.....	34	0
Shale, soft (B).....	bed mark-	2	Shale, rich.....		10
Shale, rich (A).....	ed "B," 25	½	Shale, sandy, platy, lean to barren.....	37	0
Shale, soft (B).....	gallons).....	5	Shale, rich.....		10
Shale, rich (A).....		1½	Shale, barren.....		6
Shale, lean.....		1	Shale, hard, rich.....		1
Shale, hard, rich (sample 85; 22 gallons).....		1	Shale, platy, barren.....	5	0
Shale, lean mostly, with rich layers too thin to sample.....		7	Shale, hard, rich.....		2
Shale, hard, rich (sample 84; 21 gallons).....		7	Shale, for the most part gray and lean, but a few rich layers less than 1 inch thick.....	85	0
Shale, hard, lean to rich, cliff forming.....		7	Shale, papery, lean.....	8	0
Sandstone, asphaltic.....		3	Shale, platy, lean.....	3	6
Sandstone, coarse.....		1½	Shale, hard, rich.....		3
			Shale, sandy, barren.....	3	0
			Shale, hard, rich.....		2

Sections in northeastern Utah—Continued.

Location T, on north side of Hells Hole Canyon, sec. 22, T. 10 S., R. 25 E.—Continued.

	Ft.	in.		Ft.	in.
Shale, thin, platy, lean to barren.....	30	0	Sandstone.....	3	0
Oolite.....		5	Shale, gray, lean to barren.....	19	0
Shale, papery, lean.....	8	8	Oolite.....		6
Shale, hard, rich.....		1½	Sandstone, twisted and deformed.....	1	10
Shale, barren.....		6	Oolite.....		6 6
Shale, hard, rich.....		2	Shale, gray to drab, barren.....	19	0
Shale, thin, platy, barren.....	16	0	Sandstone, massive, yellow.....	12	6
Oolite.....		4	Shale, gray.....		5 0
Shale, thin, platy, barren.....	1	2	Oolitic sandstone.....		4 0
Sandstone.....		7	Shale, sandy.....	13	0
Shale, thin, platy, barren.....	16	0	Sandstone, massive, yellow, cross-bedded.....	10	6
Cherty layers, distorted, concretinary.....	1	0	Shales, gray and drab, barren.....	45	0
Oolite, conglomerate at base.....	2	4	Sandstone, mostly yellow and massive, but with two somewhat shaly zones.....	41	0
Shale, gray and drab, barren.....	2	4	Shale, sandy, barren.....	21	0
Sandstone.....		8	Shale, rich.....		6
Shale, gray and drab, barren.....	1	10	Shale, gray and drab, barren.....	35	0
Sandstone, concretinary.....	3	6	Sandstone and barren, sandy shale.....	37	0
Shale, gray and drab, barren.....	20	0	Shale, largely masked, mostly drab, papery, with sandy zones; not sufficiently cemented to form ledges.....	95	0
Sandstone, with oolitic bands.....	4	0	Sandstone, coarse, yellow.....		1 10
Oolite.....	3	9	Shale, lean to barren, papery.....	7	0
Shale, gray and drab, barren.....	23	0	Sandstone, yellowish.....		6
Oolite, top distorted and sandy.....	3	0	Shale, soft, sandy (sample 79; 1 gallon).....	4	1
Sandstone, oolitic.....	5	0	Sandstone.....		3
Shale, gray.....	28	0	Shale, masked, but for the most part a barren greenish shale.....	26	0
Sandstone, shaly.....	15	0	Sandstone, yellowish brown, poorly cemented.....	10	0
Sandstone, massive.....	4	0	Shales, red and green (Wasatch).....		
Shale, barren, gray, sandy.....	18	6			
Oolite.....	3	6			
Shale, barren, gray sandy.....	10	0			
Oolite.....	2	0			
Sandstone.....	2	0			
Shale, barren, gray, sandy.....	65	0			
Oolite.....	1	0			
				1,047	5

The following stratigraphic sections were measured in southwestern Wyoming and show the general character of the Green River formation in the southern parts of the Green River and Southern Red Desert basins:

Sections of parts of Green River formation in southwestern Wyoming.

T. 14 N., R. 29 W.

	Ft.	in.		Ft.	in.
Sandstone, coarse grained, not massive.....	50	0	Shale, thin bedded, lean.....	14	6
Sandstone, containing fossil shells.....		4	Shale, thin bedded; weathers blue; rich.....		2 0
Sandstone, coarse grained, thin bedded.....	10	0	Shale, gray, sandy (not included in sample).....		1 7
Covered, probably sandy shale.....	35	0	Sandstone, yellow (not included in sample).....		1
Sandstone, coarse.....	8	0	Shale, thin bedded; weathers blue; rich.....		3 0
Covered, mostly shale.....	30	0	Shale, yellow, sandy.....	28	0
Shale, papery, drab, lean.....	5	0	Shale, papery, lean.....	40	0
Shale, thin, barren and sandstone.....	72	0	Shale, drab, fissile.....	10	0
Shale, drab, thin, lean.....	3	0	Sandstone, concretinary.....	1	0
Shale, thin, drab, barren.....	20	0	Shale, drab, papery.....	13	0
Shale, thin, lean.....	30	0			
Sandstone, concretinary.....	1	0			
Shale, thin, lean.....	14	0			
Oolite and chert.....	0				

*Sections of parts of Green River formation in southwestern Wyoming—Continued.***T. 14 N., R. 99 W.—Continued.**

	Ft.	in.		Ft.	in.
Oolite.....		6	Sandstone, shaly, yellowish.....	1	0
Shale, drab, papery.....	10	0	Shale, drab, papery, barren.....	5	0
Sandstone, oolitic.....		4	Sandstone, shaly, yellowish.....	1	6
Shale, drab, fissile.....	12	6	Shale, greenish drab.....	37	0
Sandstone, micaceous.....	1	0	Maroon clay shale (probably Wasatch).....		
Sandstone, yellowish.....	3	0		489	10
Shale, drab, thin sandstone lenses.....	26	0			

T. 13 N., R. 108 W.

	Ft.	in.		Ft.	in.
Sandstone, ferruginous, containing fossil shells.....		6	Shale, light brown, lean (sample 98; 3 gallons).....	5	0
Shale and sandstone.....	500±		Interval.....	25	0
Shale, thin, brown.....	5±		Shale, lean (?).....	10±	
Shale, thin, brown (sample 100; 3 gallons).....	5	0	Shale, dark brown (sample 95; 13 gallons).....	5	0
Shale, thin, brown.....	2	6	Shale, thin bedded, tough.....	10	6
Shale, hard, black, rich.....		½	Shale, thin bedded, tough (sample 96; 4 gallons).....	5	4
Shale, brown, soft.....		5	Shale, thin bedded, tough.....	2	6
Shale, hard, black, rich.....	(sample 99; 19 gallons).....	1	Shale, massive, light brown.....	2	6
Shale, brown, soft.....		8	Shale, massive, light brown (sample 97; 6 gallons).....	4	10
Shale, hard, black, rich.....		2	Shale, lean.....		
Shale, brown, soft.....		1			
Shale, hard, black, rich.....		3		586	11½

Sec. 27, T. 17 N., R. 106 W.

	Ft.	in.		Ft.	in.
Shale, drab.....	45	0	Covered, mostly light-colored shale or clay.....	75	0
Sandstone, platy.....	16	0	Clay, mostly gray, with some red.....	80	0
Shale, lean.....	22	0	Clay, gray, yellow, green, and red, with beds of yellow sandstone. All beds very lenticular. A 40-foot bed of massive sandstone at one place splits and within 100 yards along its outer top is represented by variegated clay beds, with a few thin sandstones.....	75	0
Sandstone, brown, platy.....	7	0			
Shale, hard, not so rich.....	24	0		479	10
Shale, hard, thin, platy ^a (sample 118; 14 gallons).....	5	6			
Shale, hard, dark ^a	2	3			
Shale, hard, dark, rich ^a (sample 117; 19 gallons).....	8	1			
Shale, weathers to thin plates; part of member will yield small amount of oil.....	120	0			

Secs. 17 and 19, T. 17 N., R. 106 W.

	Ft.	in.		Ft.	in.
Sandstone, massive, brown, coarse (Tower sandstone of Powell).....	125	0	Shale, hard, thin, medium rich.....	1	6
Sandstone, thin bedded.....	35	0	Shale, barren.....	15	0
Shale, papery, gray.....	25	0	Shale, medium, with large gypsum crystals.....	1	6
Sandstone, shaly, gray.....	32	0	Shale, thin, barren.....	80	0
Shale, sandy, lean.....	65	0	Shale, medium, with gypsum crystals.....	8	
Shale, hard; contains fish remains (sample 120; 14 gallons).....	5	0	Shale, gray, sandy.....	26	0
Shale, lean.....	20	0	Shale, medium, with gypsum crystals.....	1	6
Shale, thin with lenses of very rich waxy shale.....	55	0	Shale, hard, rich.....	10	
Shale, hard.....	15	0	Sandstone, thin, gray.....	8	0
Shale, hard (sample 119; 12 gallons).....	5	0	Shale, hard, rich.....	10	
Shale, hard, lean.....	12	0	Shale, gray, sandy.....	17	0
Shale, gray, sandy.....	20	0	Shale, hard, rich.....	2	
Shale, hard, rich.....	1	4	Shale, thin, gray, sandy.....	9	2
Shale, gray, sandy, thin sandstones, and a few 1 to 3 inch beds of rich shale.....	90	0	Shale, hard, rich.....	0	
			Shale, sandy.....	118	0
			Sandstone, gray.....	4	0
			Shale, sandy, greenish.....	6	0

^a Probably same zone as lower 22 feet 8 inches of section measured in secs. 17 and 19 of this township.

*Sections of parts of Green River formation in southwestern Wyoming—Continued.***Secs. 17 and 19, T. 17 N., R. 106 W.—Continued.**

	Ft. in.		Ft. in.
Sandstone, gray, thin bedded.....	1 0	Shale, lean to barren.....	75±
Shale, sandy, green.....	27 0	Shaly sandstone, barren.....	15 0
Shale, sandy, thin bedded, gray.....	21 0	Shale, sandy, forming slope, lean.....	47 0
Sandstone and shale, green, in beds 2 feet thick; sandstone, concretionary.....	58 0	Shale, hard (sample 114, lower 4½ feet; 11 gallons).....	5 6
Shale, sandy, gray, slope.....	97 0	Shale, hard (sample 113; 10 gallons).....	5 3
Sandstone, massive, cross-bedded, forming ledge and capping hill.....	5 0	Shale, hard.....	1 4
Shale, forming slope.....	43 0	Sandstone.....	3
Sandstone, rather massive, forming ledge.....	10 0	Shale, fairly soft, thin-bedded.....	2 9
Shale, soft, thin, platy, barren.....	30 0	Shale, hard.....	1 0
Shale, medium hard, rather thin, very lean.....	4 11	Shale, hard, rich (sample 111; 19 gallons).....	5 4
Shale, medium hard (sample 116; 4 gallons).....	4 10	Shale, hard, rich (sample 110; 19 gallons).....	6 3
Shale, sandy, lean to barren.....	70 0	Shale, soft.....	7
Shale, medium hard, very lean.....	10 0	Shale, hard, rich.....	2 5
Shale, lean.....	4 6	Shale, soft.....	6
Sandstone, brown, persistent.....	8	Shale, hard, rich.....	2 3
Shale, lean.....	3 0		
Shale, hard to medium hard (sample 115; 9 gallons).....	4 6		1,360 10

Along Bitter Creek, T. 18 N., R. 107 W.

	Ft. in.		Ft. in.
Sandstone, massive, brown.....	135 0	Shale, greenish gray.....	21 6
Shale, lean to barren.....	3 0	Sandstone, thin bedded.....	11 0
Shale, hard.....	0 0	Covered, mostly barren gray sandy shale, with a few ledges of gray shaly sandstone.....	128 0
Sandstone, brown, massive.....	1 0	Sandstone, platy.....	3 0
Shale, lean to rich.....	1 0	Shale, greenish.....	7 0
Sandstone, brown, massive.....	5 0	Covered, mostly barren gray sandy shale, with a few ledges of gray shaly sandstone.....	110 0
Shale, lean, papery.....	11 0	Shale; weathers papery.....	1 6
Sandstone.....	2	Sandstone.....	6
Shale, hard, rich.....	6	Shale; weathers papery.....	2 0
Sandstone.....	3	Shale, gray, sandy, with layers of shaly sandstone.....	21 0
Shale, hard, dark.....	8	Shale, greenish.....	20 0
Shale, brown, tough.....	4	Shale, gray, sandy, with layers of shaly sandstone.....	17 0
Shale, hard, rich, dark.....	1 4	Shale, greenish, with brown sandstone lentils.....	20 0
Sandstone.....	3	Sandstone, brown, with some clay shale.....	35 0
Shale, hard, rich.....	2 6	Sandstone, thin, platy.....	4 0
Shale, hard, rich (sample 127; 18 gallons).....	6 3	Sandy shale and shaly sandstone, gray, barren.....	85 0
Sandstone.....	6		755 5
Shale, hard, rich.....	6 2		
Sandstone, hard, massive.....	6		
Shale, hard, gray, sandy, lean to barren.....	13 0		
Shale, soft, greenish, lean.....	15 0		
Partly masked, barren gray shale and sandstone, with some lean papery shale.....	55 0		
Sandstone, platy.....	2 0		
Shale, lean, soft.....	2 6		

White Mountain, sec. 36, T. 19 N., R. 106 W.

	Ft. in.		Ft. in.
Sandstone, brown, coarse (tower sandstone of Powell).....	245 0	Shale, sandy, gray, and shaly sandstone.....	22 0
Shale, gray, sandy, and shaly sandstone, with three beds of rich shale each 3 inches thick in lower part.....	265 0	Sandstone, shaly, yellow.....	2 0
Shale (estimated yield, 12 to 15 gallons).....	3 0	Shale, sandy, and clay, with a few thin sandstone beds; color predominantly white.....	133 0
Shale, gray, sandy, and thin sandstone with two or three 1-inch beds of rich shale.....	37 0	Sandstone, green, shaly.....	33 0
Sandstone, gray, ripple marked.....	1 0	Shale, gray, sandy, and thin sandstone.....	58 0
		Shale, green, sandy, and green sandstone.....	17 0
		Shale, greenish drab, sandy.....	35 0
		Sandstone, chalky, cross-bedded, brown.....	2 0

Sections of parts of Green River formation in southwestern Wyoming—Continued.

White Mountain, sec. 36, T. 19 N., R. 106 W.—Continued.

	Ft.	in.		Ft.	in.
Shale, drab, sandy.....	95	0	Shale, sandy, gray.....	24	0
Sandstone, ferruginous.....	4		Sandstone, shaly, gray, fossiliferous.....	2	0
Shale, sandy, gray-green, and shaly sandstone.....	75	0	Shale, carbonaceous.....	8	0
Sandstone, shaly.....	2	0	Clay, sandy, gray.....	40	0
Shale, papery, lean, with 2-inch beds of rich shale and some thin beds of sandstone.....	87	0	Sandstone, coarse, gray, possibly base of Green River formation.....	1	0
Sandstone, with clay balls.....	6		Clay, somewhat sandy, gray.....	55	0
Shale, papery, lean.....	26	0	Shale, clay, variegated, red at top.....	33	0
			Sandstone, yellowish green, friable.....	30	0
				1,331	10

Fossil Butte.

	Ft.	in.		Ft.	in.
Sandstone, shaly.....	95	0	Shale, white, chalky.....		10
Sandstone, coarse, brown.....	3		Shale, hard, brown.....		6
Shale, hard, rich, dark; weathers blue (sample 131; 50 gallons).....	2	0	Shale, white, chalky; contains abundant fish remains.....	129; 8 gal-	
Sandstone, shaly.....	7	0			1 2
Shale, hard, rich; weathers blue.....	1	0	Shale, lean, thin bedded.....	18	0
Alternating bands of coarse sandstone and shale.....	8	0	Sandstone, drab.....	10	0
Sandstone, cherty.....	10		Shale, sandy.....	5	0
Shale, lean, chalky, thin bedded.....	15	0	Sandstone, coarse.....	65	0
Sandstone, reddish brown.....		8		250	1½
Shale, lean, chalky, thin bedded.....	2	6			
Sandstone, massive.....	8	6			
Chalk.....		3			
Sandstone, massive, yellow.....	3	2			
Shale.....		10			
Sandstone, gray (discarded).....		5			
Shale, hard, light brown.....	1	7			
Sandstone, light brown (discarded).....		4			
Shale, hard, brown, rich; weathers blue.....	1	1			
Sandstone, yellow.....		½			
Shale, hard, brown, rich; weathers blue.....		11			

STRUCTURE.

Northwestern Colorado and northeastern Utah.—The Uinta Basin is a broad, shallow syncline whose central portion is occupied by the Green River and younger formations. The Green River beds are only slightly tilted at most places around the margin of the basin, but the older formations dip at much greater angles only a few miles beyond the limits of the Green River formation. The Douglas anticline, which extends southward from Rangely, brings up the Mesa-verde and Wasatch formations and perhaps entirely separates the main Colorado area of the Green River formation from the much larger area in northeastern Utah, and it is almost certain that the areas of oil-yielding shale are completely separated. Although the Green River formation dips sharply (maximum observed dip 28°) toward the interior of the basin at its margin along the north and east sides of the Colorado area, the dip decreases very rapidly,

so that a few miles back of the margin the shale is horizontal or dips only slightly.

Small faults were observed at a few places, although it is probable that the broad movement which produced the great synclinal structure gave rise to fracture zones or cracks and faults at many other places. The great veins of gilsonite in the vicinity of Dragon, Utah, are cracks filled with the asphaltic material. West of the Petrolite Hills, in the eastern part of the area studied, a fracture zone cutting the Green River formation is filled with a very light yellowish-brown hydrocarbon (specific gravity 1.06) which does not answer the description of any of the ordinary asphaltites. The deposit may not be sufficiently extensive to be of economic importance, but it is of considerable scientific interest. The fracture zone in which the material is found is 2 or 3 feet wide and has been traced for several miles in a

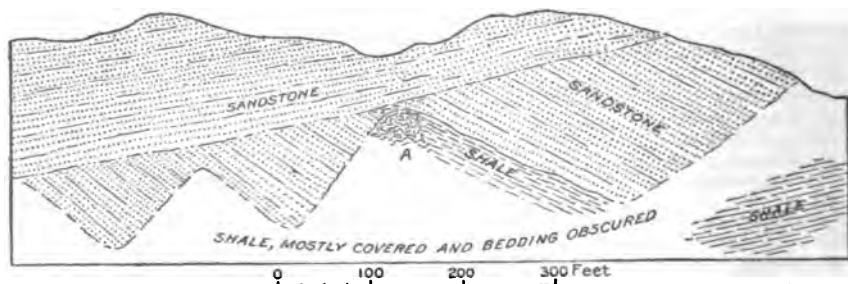


FIGURE 14.—Diagram showing structure in the Green River formation near the mouth of Yellow Creek, Colo.

general northwest-southeast direction. Several small prospects have been opened along it.

On Yellow Creek, sec. 15, T. 2 N., R. 99 W., a heavy brown sandstone rests on a very irregular surface, and the shale beneath (A, fig. 14) is very much distorted, exhibiting in places very definitely overturned folds, as well as faults on a small scale. It is not at all impossible that the brown sandstone marks the base of a formation which should be separated from that below, but in this paper it is included in the upper part of the Green River formation. The massive sandstone appears to fill channels, yet the distorted condition of the shale beneath would suggest that the shale was still in a plastic condition after the deposition of part of the sand and that the sand settled unevenly, giving rise to the many peculiar forms which are exhibited in the shale beds beneath. After this settling the deposition of sand was continued over the edges of the portions of the sand which had been displaced. This appears to represent a change in conditions of deposition which may have more than local importance.

Southwestern Wyoming.—That part of southwestern Wyoming (see Pl. X) lying between the Uinta Mountains on the south and the Wind River Mountains on the north is in a broad structural basin which is separated into several smaller basins by north-south uplifts. Oil-yielding shale is present in three distinct areas; the central area, to which the name Green River basin is applied, is by far the largest. The Rock Springs uplift, on the east, described by Schultz,¹ and related features near the Colorado-Wyoming State line, to the south-east, separate the main area from the much smaller Southern Red Desert Basin, only the rim of which is shown on Plate XIX (in pocket). On the west the Green River basin is separated from the area of the Green River formation in the vicinity of Fossil, described by Veatch² as the Fossil syncline, by an anticlinal fold which the same author called the Meridian anticline.

Beds of the Green River formation are only slightly tilted in any part of the area shown on Plate XIX. Along the western rim of the Southern Red Desert Basin the oil shale at its outcrop dips as much as 11° NE., but it flattens rapidly toward the center of the basin. Along the east and west sides of the main Green River basin the oil-yielding shale shows dips not exceeding 3° or 4°, but in some places along the north flanks of the Uinta Mountains the beds of the Green River formation are tilted at greater angles. The oil shale of the Fossil syncline is practically horizontal at every point examined.

Faults in the Green River shale were noted in only one area, but they may be present at many other places within the area here described. West of Green River, near the center of T. 15 N., R. 108 W., there is an area perhaps half a mile wide and extending an unknown distance to the west, where the rocks are crumpled and cut by east-west trending faults. On both sides of this disturbed zone the strata are apparently unaffected.

The channel sandstone of Lee,³ which is the Tower sandstone of Powell,⁴ forms vertical cliffs in the vicinity of Green River, Wyo., where it rests on an irregular surface of shale and is itself very much distorted, whereas the shale beneath is not deformed.

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The literature of oil shale is confined largely to reports dealing with the shale of foreign countries, very little having been published on that of the United States. The reports that treat of the methods of

¹ Schultz, A. R., The southern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 381, pp. 218-220, 1910.

² Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: U. S. Geol. Survey Prof. Paper 56, pp. 108-110, 1907.

³ Lee, W. T., and others, Guidebook of the western United States, Part B, The Overland Route: U. S. Geol. Survey Bull. 612, p. 74, 1915.

⁴ Powell, J. W., Geology of the eastern portion of the Uinta Mountains, pp. 40, 45, U. S. Geol. and Geog. Survey Terr., 2d div., 1876.

mining and distilling oil shale in Scotland, France, and New South Wales are especially interesting and instructive in view of the probable development in the near future of an oil-shale industry in the United States. The following list of reports includes a large number of rather extensive articles on oil shale of different localities, as well as numerous brief notes on the occurrence of shale in more or less isolated areas. The list includes most of the important reports that have been published.

ALLEN, A. H., On the relative proportions of olefines in shale and petroleum products: *Analyst*, vol. 6, pp. 177-180, 1881.

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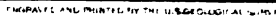
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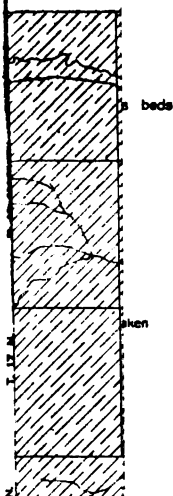
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Bulletin 641—G

**GEOLOGY OF THE UPPER STILLWATER BASIN
STILLWATER AND CARBON COUNTIES
MONTANA**

WITH SPECIAL REFERENCE TO COAL AND OIL

BY

W. R. CALVERT

Contributions to economic geology, 1916, Part II

(Pages 199-214)

Published November 17, 1916



WASHINGTON

GOVERNMENT PRINTING OFFICE

1916

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LOGY OF THE UPPER STILLWATER BASIN, STILLWATER AND CARBON COUNTIES, MONTANA, WITH SPECIAL REF- ERENCE TO COAL AND OIL.

By W. R. CALVERT.

INTRODUCTION.

In 1907 a coal field on the west side of the Bighorn Basin, Wyo., was examined by the United States Geological Survey, and the investigation was extended northward to include the coal-producing region in the vicinity of Red Lodge, Mont. Mapping was discontinued at Rock Creek, however, and no definite information was obtained relative to the westward extent of the coal field beyond that stream. It had been reported at Nye, on Stillwater River, and it was considered possible that this coal bed and some one of those developed at Red Lodge were identical. In 1908 the writer extended the investigation of the previous year westward from Red Lodge with the object of ascertaining whether the coal beds at Red Lodge and at Nye were of the same geologic age and whether they are continuous in the intervening area.

Time has not been available from 1908 until now to prepare for publication the data obtained in the field examination. In consequence the notes on the coal development here given are incomplete, they refer to conditions during and prior to 1908. The chief object of this paper is to discuss the geologic conditions in the field and the relation of the coal at Nye and Red Lodge.

In common with other investigations of Rocky Mountain coals made by the United States Geological Survey in recent years, examination was made primarily for the purpose of classifying the land with respect to coal. In the field, therefore, land lines were followed wherever it was feasible, and locations were checked from time to time by established land corners. The topography was checked by plane-table methods, an aneroid barometer being used for vertical control.

In the field the writer was assisted by F. H. Kay and E. F. Schramm and in the office by Mr. Kay in the compilation of data obtained.

SURFACE FEATURES.

The area to which this report relates lies adjacent to and north of the Beartooth Mountains and extends westward from Rock Creek to Stillwater River. It contains about 300 square miles. (See Pl. XX.)

The surface of the field is considerably diversified, including broad terraces and areas of rolling or much dissected country. On the south it is bordered by the rugged Beartooth Mountains. Glaciation has done much to modify land forms in the vicinity of the mountains, as nearly every stream valley and interstream divide is filled or covered with glacial débris. Aside from the mountainous tract the roughest topography is seen in the western part of the field, where the interstream areas rise to an altitude of 6,000 feet, or 1,000 feet above the valleys. The lowest place is in the extreme northeast corner of the field, where the altitude is about 4,600 feet above sea level. From this locality the surface rises toward the south and culminates in the high peaks of the Beartooth Mountains, whose glacier-crowned summits reach a maximum altitude of over 12,000 feet, the highest in the State. Mapping was not extended southward beyond the base of the mountains, where the altitude is uniformly about 6,000 feet.

The field as a whole is well drained by perennial streams flowing from the mountains. The largest of these are Rock, East and West Red Lodge, East and West Rosebud, and Fishtail creeks and Stillwater River, all direct or indirect tributaries of the Yellowstone.

Red Lodge is the largest town in the area, having a population of about 4,860. Other post offices are Luther, on West Red Lodge Creek; Dean, on a branch of Fishtail Creek; and Nye, near the junction of West Stillwater River with the main stream. Red Lodge is connected with the transcontinental line of the Northern Pacific Railway by a branch from Laurel, about 16 miles west of Billings. Transportation from other parts of the field is effected by wagon to points on the Northern Pacific.

GEOLOGY.

STRATIGRAPHY.

The rocks of the area comprise a great thickness of strata ranging from coal measures of lower Montana (Upper Cretaceous) age to beds more than 8,000 feet up in the Fort Union formation of the Eocene. Older sedimentary formations and crystalline rocks are exposed in the Beartooth Mountains, along whose north base there is a profound fault that brings Paleozoic rocks into contact with Tertiary formations south of Red Lodge and with successively older strata to the west. The geology of this area is shown on Plate XXI.

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CRETACEOUS SYSTEM.

EAGLE SANDSTONE AND LIVINGSTON FORMATION (UPPER CRETACEOUS).

The oldest rocks in the area consist of a white sandstone about 300 feet thick, the upper part of which is massive and grades downward into a sandy shale. The entire thickness of this sandstone occurs only in the western part of the field, but the upper portion is exposed locally as far east as sec. 4, T. 6 S., R. 18 E. A carbonaceous zone, locally coal bearing, occurs at the top of the sandstone. This white sandstone is overlain by a mass of greenish or brownish sandstone and sandy tuffaceous shale about 3,200 feet thick in the central part of the area. On examination these overlying beds appear to be highly andesitic in character and therefore to have been derived from volcanic rocks. These andesitic strata are exposed over a considerable area in the western part of the field. On West Rosebud Creek poorly assorted volcanic agglomerate, also of andesitic material, appears as a thin wedge in the midst of the tuffaceous beds, and this agglomerate thickens westward until in the vicinity of Stillwater River it is about 2,000 feet thick. In spite of this notable thickening and the fact that the base of the agglomerate is uniformly about 625 feet above the base of the andesitic beds, the stratigraphic distance between the agglomerate and the overlying Tertiary beds (Fort Union formation) remains fairly constant. A section of the andesitic beds measured in T. 5 S., R. 18 E., where the agglomerate is absent, is as follows:

Section in T. 5 S., R. 18 E.

	Feet.
Sandstone, brownish, platy, and sandy shale (thickness estimated).	1, 500
Sandstone, platy, brownish gray, with layers of chocolate-colored concretions as much as 1 foot in diameter.....	99
Partly concealed; lower 100 feet is yellowish-brown platy sandstone and yellowish sandy shale.....	287
Sandstone, very irregular in lithology and bedding, coarse grained to pebbly.....	55
Sandstone, brown, and sandy shale.....	120
Partly concealed; where exposed consists of brown sandy shale and thin brown sandstone.....	880
Sandstone, gray or brown, with intercalated yellowish shale; texture and bedding variable, chiefly fine grained and tuffaceous, with plant fragments.....	214
Shale and thin platy sandstone, brownish gray, compact and fine grained.....	11
Sandstone, thin bedded, coarse grained.....	39
Shale, gray and yellow, with thin sandstone and lignitic bands....	28

3, 233

On Stillwater River the section of the andesitic beds differs from that given above and comprises about 625 feet of shale and sandstone, 2,000 feet of agglomerate, and 2,500 feet of shale and thin sandstone,

all highly andesitic. All of this section is not exposed in the area mapped but is shown on each side of Stillwater Valley farther north-east.

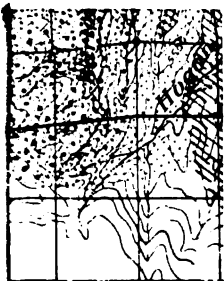
Considerable interest attaches to the age of the basal coal-bearing sandstone and the overlying andesitic beds. Fossil leaves are present in both formations, although they are confined chiefly to rocks closely associated with the coal bed of the massive sandstone and to the andesitic beds underlying the agglomerate. These leaves are similar to those found in the vicinity of Livingston, about 35 miles northwest of Nye, and the rocks containing them are therefore to be correlated with similar plant-bearing beds at Livingston. In that locality the rock section consists of a mass of shale about 3,600 feet thick, which has been considered by previous writers to be the representative of the Colorado shale, Pierre shale, and Fox Hills sandstone. Overlying this mass of shale at Livingston is a coal-bearing sandy formation about 800 feet thick that contains fossil leaves similar to those found in the coal measures near Nye. Next higher stratigraphically is a mass of andesitic rocks about 5,000 feet thick, near the base of which occur leaves of the identical species found in the andesitic beds east of Stillwater River. In earlier reports the coal measures at Livingston were considered to be of Laramie age and the andesitic rocks above, termed the Livingston formation, were supposed to have been deposited after a period of orogenic movement following the Laramie. According to this interpretation the coal-bearing sandstone at Nye should be considered Laramie and the overlying andesitic rocks to be of Livingston age. Regional study by R. W. Stone and the writer, however, leads to the conclusion that the stratigraphy at Livingston has been misinterpreted. Colorado fossils have been found at the top of the mass of shale that constitutes the lowest formation in the section as described, and it therefore appears that the coal-bearing sandstone at Livingston is of lower Montana age rather than Laramie, as has been previously supposed. Furthermore, no unconformity was found between the coal measures and the overlying Livingston formation, and there is evidence of continuous deposition from Colorado time into Fort Union time. The present interpretation is that the coal measures near Livingston are of lower Montana age, and that the Livingston formation itself is the time equivalent of the Claggett, Judith River, Bearpaw, and possibly even younger formations as developed elsewhere in the State, and is therefore of Upper Cretaceous and Eocene age.

In this report, therefore, the coal measures in the vicinity of Nye are assigned to the Eagle sandstone, the lowest formation of the Montana group. As the overlying rocks up to the Fort Union can not be separated on the basis of either lithology or paleontology the term Livingston formation will be applied to them, although it is to be under-

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stood that by the use of this name no attempt is made to convey an idea of distinct geologic time. It is not appropriate to discuss in this report all the details on which are based the present interpretation of the stratigraphic questions involved, and the reader interested in the subject is referred to a paper in which the problem is treated at greater length.¹ In any event, however, it has been ascertained beyond question that the coal measures at Nye are not in the same geologic formation as those at Red Lodge, but are nearly 9,000 feet lower.

TERTIARY SYSTEM.

FORT UNION FORMATION (EOCENE).

The rocks in the eastern part of the field, aside from surficial material and those of an area of about 5 square miles south of Linley, represent fresh-water deposits of Fort Union age, which are predominantly sandy. Woodruff² has separated the Fort Union formation of this region into three members, the division being based on the presence or absence of valuable coal beds. The lowest member consists of variable yellowish sandstone and shale 5,700 feet thick, in which no coal of any consequence occurs. Above is a member 825 feet thick, which is lithologically similar in appearance to the underlying member, but which contains several beds of coal. The upper member, about 2,000 feet thick, is also of essentially the same character as the lower, and likewise differs from the middle member in that it contains no valuable coal beds. Although it is likely that the lower part of the section should be referred to the Lance formation ("Ceratops beds"), fossils belonging to that formation were not found, and as there is no distinct change in lithology in the mass of rocks described, the entire sequence is tentatively designated Fort Union.

LINLEY CONGLOMERATE (POST-EOCENE).

In addition to the Eagle sandstone, the Livingston and Fort Union formations, as previously described, other rocks are represented in the area. Between Linley and the Beartooth Mountains is an area of about 5 square miles in which a conglomeratic sandstone lies with marked unconformity on tilted and eroded Fort Union rocks. The conglomerate is bedded throughout and is composed mainly of grains and well-rounded pebbles, 6 inches or less in diameter, of greenish porphyry, with smaller amounts of limestone and pink granite, all presumably originating in the Beartooth Mountains. The strata appear to dip at a moderate angle to the northeast, but this dip is considered to be the original attitude of deposition rather than the result of subsequent structural disturbance. It is difficult

¹ Stone, R. W., and Calvert, W. R., The stratigraphic relations of the Livingston formation of Montana: Econ. Geology, vol. 5, Nos. 6, 7, and 8, 1910.

² Woodruff, E. G., The Red Lodge coal field, Mont.: U. S. Geol. Survey Bull. 341, pp. 92-107, 1907.

to determine the thickness of this conglomerate, but it attains an approximate maximum of 300 feet. Toward the north it thins to a mere film. Although erosion has now separated the conglomerate from the Beartooth Mountains, its southern border no doubt formerly extended to that uplift. Because of the development of this conglomerate in the vicinity of Linley, it is here designated the Linley conglomerate.

No fossils were found in the conglomerate, and its age is therefore uncertain. Its superposition on highly tilted Fort Union rocks indicates that it is considerably younger than the Fort Union and also more recent than the major structural disturbances of the region. That it is not of glacial age or origin is indicated by the evenly bedded and solidified character of the rocks, by the entire absence of striæ, and by the superposition of undoubted glacial drift along the eastern margin of the conglomerate. The date of the deposition of the Linley conglomerate is rather to be correlated with the period when erosion had laid bare the crystalline core of the Beartooth Mountains and when streams emerging from the uplift had much greater gradient and carrying capacity than at present. The conglomerate was laid down as a fan or delta deposit by Red Lodge Creek at the locality where its gradient was suddenly lowered on emergence from the mountainous area. Criteria to determine the date of this condition are not available, and the Linley conglomerate is therefore merely referred to the post-Eocene.

QUATERNARY SYSTEM.

Glacial drift covers a considerable part of the area and effectually conceals all older sediments wherever it occurs. This drift is made up of lateral and terminal moraines, outwash, and other forms of glacial débris. On the recession of the glacier that once occupied Stillwater Valley a lake was formed, and along its borders were strewn boulders, probably left by floating ice; the lake floor was also covered by débris, which now conceals the underlying rock. Terrace gravel occupies the surface in much of the eastern part of the field.

IGNEOUS ROCKS.

Two areas of intrusive andesite were noted in the vicinity of Dean post office—one in secs. 13 and 14, T. 5 S., R. 16 E., and the other in secs. 15, 16, and 17, T. 5 S., R. 17 E. These rocks were not examined in detail, but as they cut the lower part of the Livingston formation they must have been intruded at a later date than the deposition of that material, and they were probably intruded before the movement which resulted in the formation of the Dean anticline.

STRUCTURE.

The structure in the eastern part of the field is relatively simple. At Red Lodge the strata associated with the coal beds dip at an angle of 18° toward the Beartooth Mountains, but the angle decreases as the mountains are approached. The beds are finally terminated by a fault of great throw which extends northwestward along the base of the mountains entirely across the field. Near Red Lodge Paleozoic limestone standing vertical occurs just south of the fault line, but farther west younger rocks up to and including the Jurassic appear, indicating that the throw of the fault lessens in that direction.

North of Red Lodge the strike of the beds remains fairly constant in direction, although interrupted by minor flexures. The dip gradually decreases, however, and at the northern border of the area it is less than 5° . Because of this decrease in dip the entire thickness of the Fort Union is not exposed in the area surveyed, and the total of 8,500 feet assigned to the formation was measured northeast of Red Lodge.

Minor faults and folds are numerous in the district west of Rock Creek and northwest of Red Lodge. These local structural features were generally not mapped, however, as the lack of persistent well-defined key beds rendered it practically impossible to work out the structure in detail. West of R. 19 E. the structure is dominated by an anticline which trends $N. 70^{\circ} W.$ to the western border of the field. East of Nye this anticline is cut by a fault. The fault can not be followed for any considerable distance, as on the east it extends into andesitic rocks where the structure is largely concealed by lack of well-defined bedding and on the west it passes under a mantle of alluvium and glacial material. The amount of vertical displacement can not be determined with certainty, but in the cliff near the south side of T. 4 S., R. 16 E., it must be nearly 600 feet. Southeast of this locality the structure seems best explained by two faults.

COAL IN THE RED LODGE DISTRICT.

FORT UNION FORMATION.

The coals at Red Lodge had been studied prior to the examination by the writer in 1908, and only one main point, that relating to the westward extent of the Red Lodge field, remained to be decided. For details regarding the coals, therefore, the reader is referred to the previous publication on this field.¹ The repetition of certain points relative to the coal, however, seems desirable. The workable

¹ Woodruff, E. G., The Red Lodge coal field, Mont.: U. S. Geol. Survey Bull. 341, pp. 92-107, 1907.

beds have a vertical range of about 800 feet and are underlain by about 5,700 feet of practically barren strata. Above them is a similar mass of sandstone and sandy shale about 2,000 feet thick which is also unproductive of coal. Measurement of the coal shows a total of 71 feet in beds more than 3 feet thick. The workable beds are known locally as Nos. 1, 1½, 2, 3, 4, 4½, 5, and 6. The coals are high-grade subbituminous coals, and compare favorably in heat value with the bituminous coals of the Mississippi Valley but do not stock so well.

The Fort Union coal beds west of Red Lodge are exposed in outcrop on both sides of Rock Creek, where they dip 18° S. and strike N. 78° W., but immediately west of the town exposures are lacking and there is nothing to indicate whether or not the structure continues regularly. Near the west quarter corner of sec. 28, T. 7 S., R. 20 E., however, a coal bed has been prospected, and though the opening was badly caved certain information was obtainable. It was noted that the strike and dip of the bed were identical with those on Rock Creek, and by sighting back along the strike it seemed probable that the bed is No. 1½, an assumption which is strengthened by the apparent thickness and character of the bed at the prospect, which is comparable to No. 1½ as developed at Red Lodge.

West of the prospect in sec. 28 exposures are not good, but the structure seems to be regular. If so, the upper coal bed meets the Beartooth fault near the east side of the township to the west, and the lower beds continue only a short distance farther. It seems likely, therefore, that the producing district at Red Lodge will be practically confined to Tps. 7 and 8 S., R. 20 E., for although the Fort Union formation constitutes the surface over a large area northwest of Red Lodge the highest strata exposed are below the productive zone.

LIVINGSTON FORMATION.

On West Rosebud Creek a carbonaceous zone near the base of the andesitic beds overlying the Eagle sandstone has been prospected at several localities, but in only one place has coal actually been removed. This is in sec. 23, T. 5 S., R. 17 E., where T. E. Philip drove an entry 250 feet long. The coal occurs here in four irregular benches with partings of bone and shale. The lower bench reaches a maximum thickness of 17 inches, and the bench above ranges from 1 inch to 13 inches. The next higher bench is termed the "rotten vein" and is worthless; the top bench is the most variable of all. This coal is not valuable, as the waste is excessive and the coal bed extremely variable and faulted. Where opened at other localities

the zone comprises only carbonaceous shale with thin partings of coal. Carbonaceous zones occur also near the top of the Livingston formation, but no coal bed was found more than 8 inches thick.

EAGLE SANDSTONE.

Coal is mined near Nye, in what is known as the Upper Stillwater Basin, from a single bed that is near the top of the massive white sandstone believed to be the Eagle. Above this are the brownish clay shale and thin tuffaceous sandstone constituting the lower part of the Livingston formation. The coal bed is exposed in outcrop in the cliff east of Stillwater River, gradually approaching the level of the valley floor, which it crosses in sec. 28, T. 4 S., R. 16 E., and it continues in a direction slightly north of west to the vicinity of the south quarter corner of sec. 19. From this locality it apparently swings to the south along the southeast base of Sheep Mountain, where it turns to the east and probably passes beneath alluvium and glacial drift. It is not known with certainty whether the bed appears elsewhere within the area, as the structure in this vicinity is complex and largely concealed by glacial débris.

Three mines have been opened on this coal bed and operated to supply a small local demand. The easternmost of these is the Albertson mine, in the SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 28, T. 4 S., R. 16 E. At this locality the coal bed is split by bone or sandstone partings into several benches, as shown in the following section, measured at a point in the mine 250 feet from the entrance:

Section of coal bed in the Albertson mine.

Sandstone.	Ft.	in.
Coal.....		10
Sandstone.....		1
Coal.....		11
Bone.....		1
Coal.....		8
Bone.....		4
Sandstone.....		4 $\frac{1}{2}$
Coal.....		7 $\frac{1}{2}$
Bone and sandstone.....	2	10
Coal.....		1
Sandstone.....		
Total coal.....	4	$\frac{1}{2}$

Sample No. 6314 (see p. 210 for analysis) was cut at this place and includes the upper three benches of coal. At the time of the examination the entry of the Albertson mine was about 250 feet long on a very slight dip. No water or gas has been encountered in the workings.

On the northwest side of Stillwater River, in the NE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 29, is the Loffer mine. Here the bed is opened by a slope 400 feet

long on a dip of 11°. The coal occurs in three benches, as shown by the following section, measured at the end of the slope:

Section of coal bed in Loffer mine.

	Ft.	in.
Sandstone.		
Coal.....	5	
Sandstone.....	2	
Coal.....	11	
Bone.....	9	
Sandstone.....	3	
Coal.....	3	3
Sandstone.		
Total coal.....	4	7

Sample No. 6320 (see p. 210) was obtained by making a cut across the three benches of coal at the place where the section given above was measured. Although under considerable cover, the coal is badly weathered near the outcrop and is not marketable for at least 125 feet from the mouth of the entry.

About three-quarters of a mile west of the Loffer mine is the Lehner opening. The entry was filled with water at the time of visit, so that an examination could not be made, but it was reported that the coal occurs in three benches, which are shown in the following section, given by a local resident:

Reported section of coal bed at Lehner mine.

	Feet.
Sandstone.	
Coal.....	1
Bone parting.	
Coal.....	1
Shale.....	2
Coal.....	3
Sandstone.	
Total coal.....	5

Aside from these three mines no development worthy of mention has been made in the vicinity of Nye. The coal bed has been prospected southeast of the Albertson mine, in the southern part of sec. 33, and shown to be of poor quality and insufficient thickness. On the opposite side of the valley, southwest of the Lehner mine, nothing is known of the coal bed. Its probable outcrop is indicated on the map (Pl. XXI) but it was not seen, and therefore the area of readily available coal in the vicinity of Nye is probably of small extent. Dips near the outcrop are comparatively slight as a rule, yet a short distance away from the outcrop the coal bed is carried by increasing dips to considerable depths. Coal is mined from a thin bed in sec. 8, T. 5 S., R. 16 E., from rocks which in lithology might belong either to the coal measures or to the overlying

andesitic beds. Fossil plants do not serve to differentiate these formations sharply, so that there is doubt as to the stratigraphic position of the coal. It is probable, however, that the bed is above the coal bed exposed north and east of Nye. On the west side of Stillwater River, outside of the area mapped, a bed of coal has been opened that is probably the same as that near Nye. It is, however, of poor quality and is not considered further in this report.

CHARACTER OF THE COAL.

The coal of the Nye district is fairly dense and rather dull in luster, though it contains brighter bands ranging from a mere film to some a quarter of an inch thick. Brown resin occurs in a few minute lenses. So far as known the coal is noncoking.

Samples were taken from the Albertson (No. 6314) and Loffer (No. 6320) mines, and their analyses, made in the United States Geological Survey laboratory at Pittsburgh, are given below.

Analyses of coal samples from the Nye coal field, Mont.

[F. M. Stanton, chemist in charge.]

Laboratory No.	Location.			Thickness.		Air-drying loss.	Form of analysis.	Proximate.				Ultimate.					Heat value.			
	Quar-ter.	Sec-tion.	T. S.	R. E.	Coal bed.			Part sam-pled.	Mois-ture.	Vola-tile matter.	Fixed car-bon.	Ash.	Sul-phur.	Hydro-gen.	Carbon.	Nitro-gen.	Oxygen.	Calories.	British thermal units.	
6314	NW...	28	4	16	7 9	Ft. in. 3 1½	2.2	A B C D	7.0	30.1	44.2	18.7	0.49	.....	.....	.....	.....	5,625	10,130	
									4.9	30.8	45.2	19.1	.50						5,755	10,360
										32.4	47.5	20.1	.53						6,050	10,890
										40.5	59.5		.66						7,575	13,640
6320	NE...	29	4	16	5 9	4 7	2.4	A B C D	6.7	32.4	44.5	16.41	.53	5.04	61.47	1.10	15.45	5,935	10,680	
									4.4	33.2	45.6	16.81	.54	4.89	62.98	1.13	13.65	6,090	10,940	
									.....	34.7	47.7	17.60	.57	4.60	65.92	1.18	10.13	6,365	11,450	
									.....	42.1	57.9	.....	.66	5.58	80.00	1.43	12.30	7,720	13,900	
3590	SE....	30	7	20	11 5	6 0	4.7	A B C D	11.7	36.1	40.2	11.98	1.05	5.26	55.46	1.20	25.05	5,435	9,790	
									7.3	37.9	42.2	12.57	1.10	4.97	58.20	1.26	21.90	5,705	10,270	
									.....	40.9	45.5	13.57	1.19	4.48	62.80	1.36	16.60	6,155	11,090	
									.....	47.3	52.7	.....	1.38	5.19	72.66	1.57	19.20	7,125	12,820	
5823	.....	6	8	21	3 11	3 9	3.3	A B C D	9.8	34.7	47.2	8.27	2.17	5.20	60.20	1.42	22.74	6,045	10,980	
									6.7	35.9	48.8	8.55	2.24	5.00	62.25	1.47	20.49	6,250	10,270	
									.....	38.5	52.3	9.17	2.41	4.56	66.74	1.57	15.55	6,705	11,090	
									.....	42.4	57.6	.....	2.65	5.02	73.48	1.73	17.12	7,380	13,280	
5495	SW...	17	6	28	7 8	3 6	3.8	A B C D	14.8	26.9	44.9	12.35	.33	5.61	57.05	.91	22.75	5,275	10,040	
									6.6	29.6	49.2	14.04	.36	5.08	62.55	1.09	16.37	6,115	11,010	
									.....	31.6	52.7	15.67	.39	4.65	66.98	1.07	11.24	6,545	11,760	
									.....	37.5	62.5	.....	.46	5.51	79.42	1.37	13.34	7,765	13,970	
5508	NE....	13	5	22	7 5	4 1	2.7	A B C D	9.7	37.7	46.2	16.42	.63	5.09	56.19	1.01	20.66	5,885	10,240	
									6.3	28.7	47.9	17.05	.65	4.86	58.35	1.05	18.04	5,905	10,630	
									.....	30.6	51.2	18.20	.70	4.44	62.27	1.12	13.27	6,300	11,340	
									.....	37.5	62.5	.....	.86	5.43	76.13	1.37	16.21	7,705	13,570	

In the table the analyses are given in four forms, marked A, B, C, and D. Analysis A represents the composition of the sample as it comes from the mine. This form is not well suited for comparisons, for the amount of moisture in the sample as it comes from the mine is largely a matter of accident and consequently analyses of the same coal expressed in this form may vary widely. Analysis B represents the sample after it has been dried at a temperature a little above the normal until its weight becomes constant. This form of analysis is best adapted to general comparisons. Analysis C represents the theoretical condition of the coal after all the moisture has been eliminated. Analysis D represents the coal after all moisture and ash have been theoretically removed. This is supposed to represent the true coal substance, free from the most important impurities. Forms C and D are obtained from the others by recalculation. They should not be used for commercial representation, for they represent theoretical conditions that never exist.

In the analytical work chemists generally recognize that it is not possible to determine the proximate constituents of coal or lignite with the same degree of accuracy as the ultimate constituents. Therefore the air-drying loss, moisture, volatile matter, fixed carbon, and ash are given to one decimal place only; whereas the ash (in an ultimate analysis), sulphur, hydrogen, carbon, nitrogen, and oxygen are given to two decimal places. It is also understood that calorific determinations to individual units are not reliable; therefore in the column headed "Calories" the heat values are given to the nearest five units, and in the column headed "British thermal units" they are given to the nearest tens, a British thermal unit being about one-half the value of a calorie.

In order to make direct comparisons with other coals of this general region analyses of some of the best-known coals have been inserted in the table. No. 3590 represents a sample from bed No. 1 in the mine of the Northwestern Improvement Co. at Red Lodge. No. 5823 represents a sample from bed No. 4 in the mine of the Bear Creek Coal Co. at Bear Creek. Both of these beds are in the Fort Union formation and hence are much younger geologically than the Nye bed in this field. Nos. 5495 and 5508 represent coal from the Bridger bed, in the eastern part of Carbon County, which occupies about the same stratigraphic position as the Nye bed. No. 5495 is the analysis of a sample from the mine of the Bridger Coal Improvement Co. and No. 5508 of a sample from Gebo No. 2 mine of the Bituminous Coal Co.

By comparison of the analyses it will be seen that the composition of the Nye coal is more nearly like that of the Bridger coal than it is like that of the coal at Red Lodge and Bear Creek. The moisture of the Nye coal is nearly the same as that of the Bridger coal and

considerably less than that of the Fort Union coals at Red Lodge and Bear Creek. The amount of volatile matter is also nearly the same in the Nye and Bridger coals and less than in those of Bear Creek and Red Lodge. Ash, on the other hand, is greater in the Nye and Bridger coals than it is in the Red Lodge and Bear Creek coals. The real value of the coal itself, aside from any impurities such as moisture and ash that it may contain, is well shown by a comparison of the heating values in the analyses of form D:

Heating values of some Montana coals.

Coal.	Laboratory No.	British thermal units.
Nye.....	6314	13,640
Nye.....	6320	13,900
Bridger.....	5495	13,970
Bridger.....	5508	13,870
Red Lodge.....	5590	12,820
Bear Creek.....	5823	13,280

From this table it is evident that the substance of the Nye and Bridger coals is superior in heating value to that of the Red Lodge and Bear Creek coals, but the higher ash content would tend to neutralize this advantage and make the two coals as they reach the market of about the same value.

These coals are doubtless near the dividing line between bituminous and subbituminous. Those of Red Lodge and Bear Creek, owing to their tendency to slack when exposed to the atmosphere, are generally regarded as subbituminous, whereas the Bridger coal, which shows little or no tendency to slack, is regarded as bituminous. It is said that the coal at Nye will stock as well as that at Red Lodge, if not better, and if this claim is in accord with the facts it appears that the Nye coal may be classified as bituminous rather than subbituminous like the Red Lodge and Bear Creek coals. This assignment of the Nye coal to the bituminous class is still further strengthened by the similarity of its composition to that of the Bridger coal as shown by the analyses.

FUTURE DEVELOPMENT.

In the Red Lodge district development is certain to be steady and continued, as a great amount of coal is known to be available and transportation facilities are entirely adequate. The coal in the Upper Stillwater Basin, however, is less fortunately situated, and the present demand is purely local. The future of this area, therefore, is dependent on future transportation facilities. Surveys have been made from Columbus, on Yellowstone River, to the headwaters of the Stillwater, the object being to build a line to Cooke City to aid in the development of the metalliferous district in that vicinity. If

this line is ever built it will afford an outlet for the coal near Nye, and as this coal compares favorably with that of competing fields, a considerable amount would no doubt find its way to market. The tonnage of available coal, however, is not comparable to that of the Red Lodge field, where there are at least eight workable beds and where the area underlain by coal within 2,000 feet of the surface is considerably greater than at Nye.

OIL PROSPECTS.

At two localities in the area mapped there have been attempts to obtain oil by drilling. One of these is in the northeastern part of sec. 4, T. 6 S., R. 18 E., and the other is in the SE. $\frac{1}{4}$ sec. 32 of the same township. At the former place several holes were put down to different depths, the deepest being 1,500 feet. After passing through surface wash and the lower sandy portion of the Eagle sandstone the drilling was in dark shale and thin sandstone, presumably of Colorado age. All the holes were dry, although indications of oil were reported. The drilling was done on the axis of an anticline, but nevertheless the absence of oil in the rock section has not been conclusively shown, first because the holes were of insufficient depth, and second because they were put down on the pitching end of the anticline. The absence of water in the drill holes, however, suggests that the beds penetrated are not charged with oil higher in the anticlinal arch and that if oil is present at any horizon through which the drill passed it has accumulated at that horizon lower down on the flanks of the anticline. All prospecting at this locality had ceased at the time of examination in 1908.

At the locality in sec. 32 there is more justification for oil prospecting, and considerable money had been expended prior to 1904, when large operations ceased, owing, it is said, to disagreement among the stockholders. One hole had been drilled to a depth of 1,100 feet and several others to about 600 feet. Indications of oil were reported in each, and it was asserted that in one hole small amounts of oil were obtained. At three points near by small pools of asphalt occur, and in 1908 these pools were being augmented by asphalt oozing from the ground.

Geologic relations in this vicinity are much obscured by thick growths of quaking aspen, but enough was observed to ascertain that the drilling was done in Fort Union rocks dipping toward the Beartooth fault at an angle of 22° . The exact location of the fault here is somewhat doubtful, owing to the covering of talus, but it is probable that the holes are about a quarter of a mile from the fault line. Because of the relation of the drill holes to the fault the original stratigraphic horizon of the oil is in doubt, and whether or not it is indigenous to the Fort Union beds with which it is at present asso-

ciated is uncertain. It seems probable, however, that the original source of the hydrocarbons was at a lower stratigraphic horizon, and that the Beartooth fault has afforded opportunities for migration upward to the pervious strata of the Fort Union. Evaporation at the surface then dissipated the volatile portion, and the residuum remains as asphalt. The fact that this bituminous residue is present at the surface suggests that oil in large quantity is not likely to be found in the strata from which the asphalt oozes. Moreover, whatever oil is present would be more likely to be encountered by drilling nearer to the Beartooth fault, but the possible oil-bearing strata would naturally be at a greater depth than is reached in the holes drilled prior to 1908.



DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 641—H

**GEOLOGY OF THE HOUND CREEK DISTRICT
OF THE GREAT FALLS COAL FIELD
CASCADE COUNTY, MONTANA**

,BY

V. H. BARNETT

Contributions to economic geology, 1916, Part II

(Pages 215-231)

Published October 9, 1916



**WASHINGTON
GOVERNMENT PRINTING OFFICE
1916**

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GEOLOGY OF THE HOUND CREEK DISTRICT OF THE GREAT FALLS COAL FIELD, CASCADE COUNTY, MONTANA.

By V. H. BARNETT.

INTRODUCTION.

This paper is based on field work done during the month of September, 1909, by W. R. Calvert and the writer, assisted by J. R. Hoats. Its objects are to give information regarding the coal resources of the Hound Creek district of the Great Falls coal field and to describe the geologic formations and the structure relating to the occurrence or absence of the coal-bearing rocks. As the work was done primarily

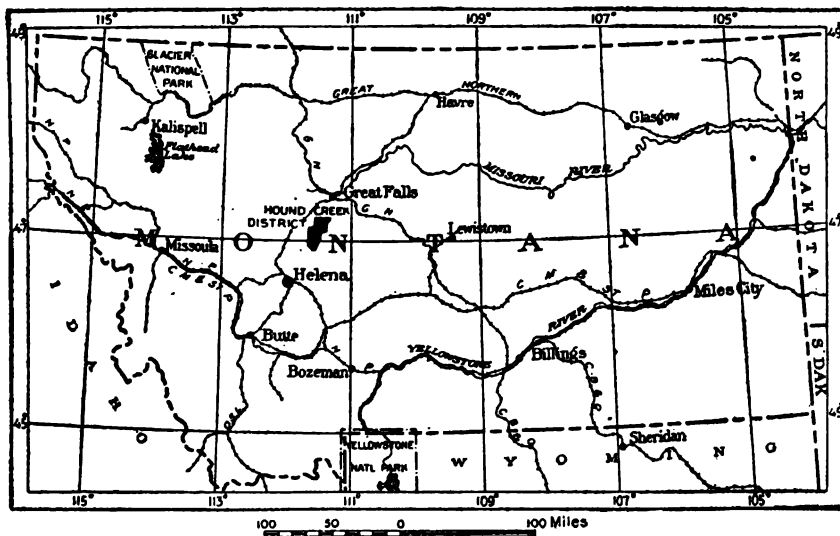


FIGURE 15.—Key map showing location of Hound Creek district, Mont.

for land classification, the determination of the presence or absence of the coal was one main purpose.

The Hound Creek district is the southwestern extension of the Great Falls coal field, on which a detailed report¹ has been published. It comprises 180 square miles in Cascade County, Mont., and extends

¹ Fisher, C. A., *Geology of the Great Falls coal field, Mont.*: U. S. Geol. Survey Bull. 356, 1909.

along both sides of Hound Creek from a point near its mouth on Smith River (Deep Creek) to the head of Elk Creek in the foothills of the Big Belt Mountains. (See Pl. XXII and fig. 15.)

In the course of the field work section corners were found with very little difficulty. Plane-table triangulation and mapping with telescopic alidade and stadia rod were also employed, so that a fair degree of accuracy was attained. Altitudes were obtained by aneroid-barometer readings based on the assumed altitude of Hound Creek bridge, in sec. 24, T. 17 N., R. 2 E.

SURFACE FEATURES.

RELIEF.

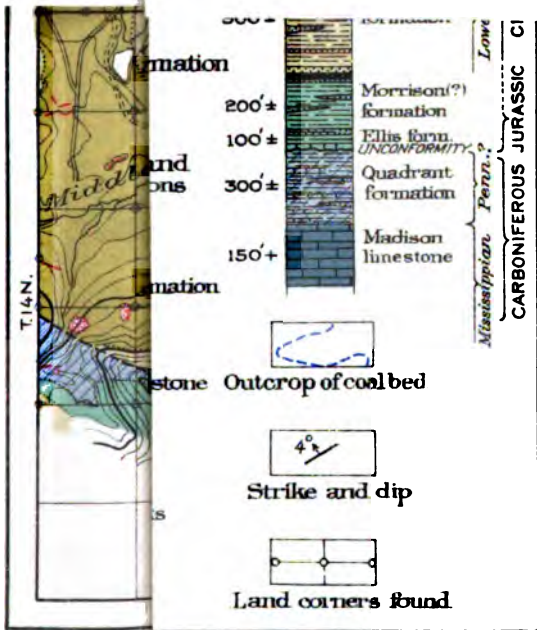
The surface of the district is made up of high, rounded hills and broad slopes cut by streams into steep-sided valleys. For the most part the area borders a zone of mountain topography, but on the north it is adjacent to a more level country. The range of altitude is from 3,800 feet near the mouth of Hound Creek to about 7,200 feet in the southern part of the district. The average altitude of the field is about 5,000 feet, and the greatest difference in any one locality is 1,200 feet in three-fourths of a mile in sec. 22, T. 15 N., R. 1 E. Most of the streams have cut deep channels into the soft shale, and the more resistant limestones and sandstones make the valley sides steep and precipitous. The deeper valleys are from 300 to 500 feet below the level of the bordering plains. Smith River is locally known as Deep Creek because it flows through a deep, narrow gorge in this part of its course. It crosses the northeast corner of the district and empties into Missouri River about 16 miles to the northwest. Hound Creek drains the larger part of the area, and its numerous mountain tributaries are fed by perennial springs.

CULTURE.

There are few settlements in the Hound Creek district, the population averaging about six families to the township. Adel, the only post office, is maintained at a ranch house in the southwestern part of the district. The location of ranches is determined by the position of readily irrigable land or by proximity of range for stock. There is an abundance of water almost everywhere, so that except on the higher areas it is not very difficult to procure sufficient water for irrigating small tracts.

Wagon roads generally are poor, but two regularly traveled roads cross the district from north to south. One is the stage road from Great Falls to Milligan post office and the other the main line of travel between Adel and Cascade, on Missouri River, 15 miles to the north. Other roads connect with these main roads but are difficult to travel over even with a light wagon.

Order of



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An electric power line from Great Falls to Butte has been constructed across this region for the purpose of transmitting power from the falls of the Missouri.

GENERAL GEOLOGY.

SEDIMENTARY ROCKS.

The rocks that crop out in the Hound Creek district belong to the Carboniferous, Jurassic, and Cretaceous systems, but detailed study was confined to the coal-bearing Kootenai formation (Lower Cretaceous). The stratigraphic position, characteristic features, age, thickness, and economic importance of the formations are given in the accompanying table:

Geologic formations in the Hound Creek district.

System.	Series.	Formation.	Lithologic character.	Thickness (feet).	Economic features.
Quaternary.		Alluvium. ^a	Silt, clay, and gravel.	2-25	Forms irrigable fertile tracts.
Cretaceous.	Upper Cretaceous.	Colorado shale.	Shale, dark, with beds of tough gray sandstone.	b 250	Contains sandstone which is resistant to weather and covers fields with loose slabs.
	Lower Cretaceous.	Kootenai formation.	Sandstone, gray, and shale and clay, red, sandy, with local beds of white limestone. The sandstone predominates in the lower part, but the red shale and clay constitute most of the upper part. Coal or shale bed 60 feet above base.	400-500	Contains locally a bed of coal.
Cretaceous (?).		Morrison (?) formation.	Shale, variegated, and clay, containing sandstone and limestone layers.	200±	Contains limestone suitable for building stone.
Jurassic.		Ellis formation.	Sandstone, tough, drab colored, conglomeratic in upper part, with some limestone underlying it.	100±	Contains sandstone and limestone probably suitable for building stone.
Carboniferous.		Unconformity			
	Pennsylvanian (?).	Quadrant formation.	Limestone, red, bluish, and greenish calcareous shales and clay, and a bed of white sandstone near top.	300±	Contains limestone probably suitable for a flux or for a building stone.
	Mississippian.	Madison limestone.	Limestone, massive, white to gray.	b 150+	Contains abundance of limestone probably suitable for building stone.

^a Alluvial deposits in the Hound Creek district occupy small tracts in valleys.

^b Exposed.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

Madison limestone.—Only the upper 150 feet of the Madison limestone is exposed in this field. It crops out in the gorge of Smith River, in the northeastern part of the district, and is the gorge-forming rock along that river for a number of miles above this area. It is also the most prominent sedimentary rock along the west slope of the Little Belt Mountains.

Weed ¹ ascribes a thickness of 1,000 feet to the Madison and divides it into three members—at the bottom the Paine shale, consisting of gray thin-bedded shaly limestones; in the middle the light-colored Woodhurst limestone, whose beds are separated by thin argillaceous layers; and at the top the massive Castle limestone.

No special study was made of the Madison in connection with the work in the Hound Creek district, and no fossils were obtained from it, but collections made by Fisher ² in 1906 in the Great Falls field, and by Calvert ³ in 1907 in the Lewistown coal field were determined by George H. Girty to be of Mississippian age.

PENNSYLVANIAN (1) SERIES.

Quadrant formation.—The Madison limestone is overlain by the Quadrant formation. The lower two-thirds of this formation consists principally of red, bluish, and greenish calcareous or dolomitic shale with irregular bands of limestone. This shale rests upon the Madison limestone, and the change in lithology is so abrupt, from the Madison beds, laid down in a deep quiet sea, to the Quadrant beds, laid down in shallow water, that an unconformity is suggested, but no stratigraphic evidence regarding it has been obtained. The upper part of the Quadrant consists mainly of bluish compact massive or thin-bedded limestone. The formation received its name from Quadrant Mountain, in the Yellowstone Park, where it is well developed.

The thickness of the Quadrant formation, according to Weed, ranges from 230 feet on Sixteenmile Creek, in the southwestern part of the Little Belt Mountains quadrangle, to 1,400 feet on Judith River, in the northeastern part of the quadrangle. Calvert ⁴ found it ranging in thickness from 425 feet to about 750 feet in the Lewistown coal field, and Fisher ⁵ noted its absence from the section at a few localities in the southern part of the Great Falls field, where, according to his statement, the Ellis formation lies unconformably upon the Madison limestone. At one locality in the Great Falls

¹ Weed, W. H., U. S. Geol. Survey Geol. Atlas, Little Belt Mountains folio (No. 56), 1899.

² Fisher, C. A., Geology of the Great Falls coal field, Mont.: U. S. Geol. Survey Bull. 356, 1909.

³ Calvert, W. R., Geology of the Lewistown coal field, Mont.: U. S. Geol. Survey Bull. 390, 1909.

⁴ Idem, pp. 15-17.

⁵ Fisher, C. A., op. cit., p. 25.

field (in sec. 34, T. 17 N., R. 3 E.) W. R. Calvert and the writer found about 190 feet of the Quadrant formation exposed. At this place a section was measured through the Quadrant formation, and fossils were found near the top and in the overlying Ellis formation. The fossils from bed 1 of the section (see below) were determined by T. W. Stanton to be *Ostrea strigilecula* White and *Camptonectes* sp., both Jurassic forms, whereas those from bed 3 of the section were found by George H. Girty to contain a single species which he determined to be *Myalina arkansana* and which he assigns to the Quadrant. The Quadrant-Ellis contact therefore must be concealed in bed 2 of the section, so that the thickness of the Quadrant formation at this place can not be more than 196 feet and may be 25 or 30 feet less.

Section of Quadrant formation on Smith River, in sec. 34, T. 17 N., R. 3 E.

	Feet.
1. Limestone, massive, irregular bedded (Ellis).....	
2. Covered (Quadrant-Ellis contact).....	36
3. Limestone, thin bedded, and shale, with few fossils.....	15
4. Limestone, bedded and massive, argillaceous, with irregular layers of chert.....	11
5. Shale, greenish, and thin beds of limestone.....	103
6. Sandstone, white, saccharoidal.....	4
7. Partly covered; red shale where exposed elsewhere.....	27
	196

The quadrant formation is variable not only in thickness but also in character. Generally the lower half is more shaly than the upper half, but red, blue, and green shales and clays occur at many levels and are replaced laterally by limestone beds.

No especial study was made of the Quadrant in the Hound Creek district, so that but few fossils were collected. Those obtained from the upper part of the formation are listed below as determined by George H. Girty.

Schizophoria? sp.
Derbya kaskaskiensis.
Myalina arkansana.

Productus semireticulatus.
Productus pileiformis.
Productus sp.

Mr. Girty states that the above forms "would not of themselves afford very satisfactory evidence for exact age determinations, but they seem to agree with more extensive collections from the same formation made by W. R. Calvert and me, which show that the fauna is very closely related to that of the interval of the Moorefield, Batesville, and Fayetteville formations of the Arkansas section, which have generally been regarded as upper Mississippian." He says, however, that there is a possibility that the rocks may prove to be of early Pennsylvanian (Pottsville) age. In areas to the south and southwest the Quadrant formation has yielded Pennsylvanian

fossils. In the absence of conclusive fossil evidence, the beds belonging to the Quadrant formation in this area are doubtfully assigned to the Pennsylvanian series.

JURASSIC SYSTEM.

Ellis formation.—Resting unconformably upon the Quadrant is the Ellis formation, made up of compact impure limestone and dull-colored sandstone. It has been described by Weed,¹ Fisher,² and Calvert.³

The formation crops out in a narrow zone over a large part of the east side of the district and along the slopes bordering many of the streams, where the resistant beds of the formation have formed escarpments in many places. The Ellis, wherever observed in this area, lies unconformably on the Quadrant formation.

The Ellis formation is almost as variable in thickness and lithology as the Quadrant. Where the full section is present the lowest part usually consists of compact limestone from 15 to 25 feet thick, and in places is separated from the upper part by a bed of calcareous shale. The upper member is usually a sandstone from 50 to 75 feet thick which is compact and locally conglomeratic in the lower part, but thin-bedded or even shaly toward the top.

The fossils collected from this formation, a list of which follows, have been determined by T. W. Stanton to belong to the Ellis formation (Jurassic).

Astarte sp.

Camptonectes sp.

Cyprina? sp.

Gervillia? sp.

Mytilus sp.

Ostrea strigilecula White.

Rhynchonella gnathophora Meek?

Trigonia sp.

Undetermined small pelecypoda.

CRETACEOUS (?) SYSTEM.

Morrison (?) formation.—The strata here tentatively assigned to the Morrison formation (named by Eldridge⁴ from the town of Morrison, near Denver, Colo.), consist of alternating beds of shale, sandstone, and argillaceous limestone. They rest conformably on the underlying Ellis formation and are overlain with apparent conformity by the Kootenai, though the line of contact between the two formations is not well defined, and the similarity of their beds, both in color and in lithology, makes it difficult to define the limits. In the Hound

¹ Weed, W. H., and Pirsson, L. V., *Geology and mineral resources of the Judith Mountains of Montana*: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 476-480, 1898. Weed, W. H., U. S. Geol. Survey Geol. Atlas, Little Belt Mountains folio, No. 56, 1899.

² Fisher, C. A., *op. cit.*, pp. 27-28.

³ Calvert, W. R., *op. cit.*, pp. 19-22.

⁴ Emmons, S. F., Cross, Whitman, and Eldridge, G. H., *Geology of the Denver Basin in Colorado*: U. S. Geol. Survey Mon. 27, p. 60, 1886.

Creek district few good exposures of the Morrison (?) formation occur. The following section was measured in this district:

Section of Morrison (?) formation in the NE. $\frac{1}{4}$ sec. 34, T. 16 N., R. 3 E.

	Feet.
Kootenai formation.	
Sandstone, hard, drab, shaly.....	12
Clay, soft, green; contains some sandstone concretions.....	17
Sandstone, hard, brown to pink, calcareous.....	6
Shale, soft, pink to red, alternating with bands of sandy and calcareous shale from 2 inches to 24 inches thick.....	115
Ellis formation.	150

Fisher¹ mapped the beds overlying the Ellis formation as Morrison because of their similarity to that formation in Colorado and Wyoming and also because they contain vertebrate fossils. This was the first recognition of the Morrison in Montana, although Weed and Pirsson,² in speaking of the beds above the Ellis formation say that "it is possible they may be equivalent to the Upper Jurassic" (Morrison formation) recognized in Colorado." Vertebrate fossils found in them by Fisher were provisionally identified by C. W. Gilmore as being of Jurassic age. Calvert³ has also mapped the Morrison in the Lewistown coal field, and the meager fossil evidence obtained in that field seems to point toward the Jurassic age of the beds, but until more evidence is at hand the age of the Morrison can not be known with certainty. Although search was made at every opportunity, no fossils were obtained during the present work, and so this paper can add nothing toward the solution of the problem.

CRETACEOUS SYSTEM.

LOWER CRETACEOUS SERIES.

Kootenai formation.—The term Kootenai, derived from the name of a tribe of Indians in the Canadian Rockies, was proposed by Dawson⁴ in 1885 for beds that occur in that part of Canada, consisting of sandstone interbedded with shale and shaly sandstone, in which there are in places layers of conglomerate and a zone of coal beds.

Two years later Newberry⁵ correlated the coal-bearing beds of the Great Falls region with Dawson's Kootenai formation of the Canadian Rockies. The question of the age of the Kootenai and the application of the term in the Great Falls and Lewistown coal fields is fully discussed in the bulletins by Fisher and Calvert, already cited.

¹ Fisher, C. A., op. cit., pp. 28-30.

² Weed, W. H., and Pirsson, L. V., op. cit., p. 480.

³ The Morrison formation is now classed by the United States Geological Survey as Cretaceous (?).

⁴ Calvert, W. R., op. cit., pp. 22-24.

⁵ Dawson, G. M., Roy. Soc. Canada Trans., vol. 3, sec. 4, p. 2, 1885.

⁶ Newberry, J. S., School of Mines Quart., vol. 8, No. 4, p. 327, 1887.

The Kootenai of this area overlies the Morrison (?) formation with apparent conformity, and the beds of the two are lithologically similar. There is, however, a predominance of red shale in the Kootenai and fewer beds of limestone than in the underlying formation. Measurement of the thickness of the Kootenai was rendered impracticable by the fact that the full section is not exposed in any one locality in the area. It is believed, however, that there is little variation in thickness from about 500 feet as measured by Fisher in the Great Falls field.

The formation is composed of red, blue, and gray shales and clays alternating with beds of sandstone and in the lower portion with thin beds of impure limestone. A coal bed is also present locally. The most prominent of the sandstone beds occurs about 60 feet above the base of the formation and is about 20 feet thick. This is the thickest bed of sandstone in the formation, and to its hardness is due much of the bench land as well as many of the loose rock slabs scattered over the surface. The coal bed, wherever present, occurs either immediately below or within 6 or 8 feet of the base of this sandstone. The beds below the coal zone consist of about 60 feet of alternating red and blue shales and thin beds of sandstone and impure limestone. The beds above the massive sandstone overlying the coal zone are composed of red, blue, and gray shales and clays alternating with gray sandstone. The red color predominates in the upper part of the formation and continues up to the base of the overlying Colorado shale. No discordance of dips at the top of the Kootenai was observed. The Kootenai occupies a broad bench in the north-central part of the district and borders Hound Creek on the west, extending to the southwestern part of the area. It is also present in isolated areas in the eastern part of the district. In the mountains bordering the district on the southwest the Kootenai formation is present, but it is complexly faulted and occupies only a small portion of the surface.

With the exception of one small collection of ferns which were too fragile to bear transportation and which were obtained from a carbonaceous shale near the coal, no fossils were found in the Kootenai of this district, but in the Great Falls field an abundant flora of Lower Cretaceous age was found by Newberry,¹ who used the fossil plants in correlating the Kootenai of this field with that of the Canadian area, and also by Fisher.² In the Lewistown field, farther east, Calvert³ observed that fossils in the Kootenai are not abundant, and the same thing is true of the area under discussion.

UPPER CRETACEOUS SERIES.

Colorado shale.—The Colorado shale, the highest formation present in the Hound Creek district, overlies the Kootenai formation and is

¹ Newberry, J. S., op. cit., p. 327.

² Fisher, C. A., op. cit., pp. 33-35.

³ Calvert, W. R., op. cit., pp. 28-29.

300 or 400 feet thick. It is composed of alternating beds of dark clay and shale with interbedded pale-yellow shaly sandstone. The base of the Colorado is marked by a heavy sandstone from 15 to 30 feet thick that is distinguishable from the sandstone of the Kootenai formation by its pale-yellowish color and finer texture; in fact, this color is fairly constant for all the sandstones of the Colorado in the region. The Colorado shale probably represents part of the beds originally described by Meek and Hayden as the Fort Benton shale. That term was derived from the name of a town on Missouri River about 40 miles below Great Falls, but the stratigraphic limits of the formation (now called Benton shale) are based largely on a section along Missouri River in northern Nebraska, where the Benton shale rests upon the Dakota sandstone and is overlain by the Niobrara limestone. The Niobrara is not separable in this region, and consequently the group term Colorado is used, Benton not being appropriate.

The exposures of the Colorado shale in this district are so poor that fossils were obtained at but one locality, in the bed of West Hound Creek, in the NW. $\frac{1}{4}$ sec. 11, T. 15 N., R. 1 E. These fossils as determined by T. W. Stanton are *Anchura* sp., *Inoceramus labiatus* Schlotheim, and *Lingula* sp., all referred by him to the Benton.

QUATERNARY SYSTEM.

No attempt was made in the Hound Creek district to map Quaternary deposits, for they are confined entirely to narrow beds of gravel along the streams and to very small alluvial deposits.

IGNEOUS ROCKS.

There are no crystalline rocks in the Hound Creek area except along the west and southwest sides. The high ridges bordering the area for nearly its entire length along the west side are hills of igneous rocks. Radiating from this igneous mass are numerous dikes and sills, most of which are small and composed of basic rocks. Little time was given to the study of these rocks, however, for they lie mostly outside of the area occupied by the coal-bearing formation.

The Colorado shale, through which the dikes cut, is not extensively altered. Alteration is confined usually to a few inches on each side of the dikes and is noticeable along a zone a few feet thick in contact with some of the igneous masses.

Specimens were collected from a few of the dikes and sills, and examined by E. S. Larsen, who describes them below.

Specimen 5, trachydolerite.—From a dike cutting the Colorado shale in sec. 31, T. 15 N., R. 1 E. The dike is about $2\frac{1}{2}$ feet thick and is traceable for about half a mile.

In the hand specimen this rock is dense and dark green. The numerous dark-green augite crystals, some of which are a centimeter in length, break out cleanly from the matrix. Small lenses of white fibrous natrolite occur. Analcite is present in rounded grains. The groundmass is finely crystalline and shows numerous cleavage faces of feldspar. The thin section reveals rather abundant phenocrysts of augite, feldspar, and analcite in a holocrystalline groundmass. This groundmass consists of feldspar laths, biotite, augite, and altered olivine. Accessory apatite and iron ore and secondary natrolite, calcite, and chlorite are present. The feldspar phenocrysts are labradorite and bytownite, and nearly all of them have a rather broad border of orthoclase; those of the groundmass are mainly orthoclase, though they likewise have a core of labradorite. The plagioclase core of the feldspar is always much altered, but the border is fresh. The analcite is probably primary and occurs as poorly developed crystals, many of which are pierced by orthoclase laths. The olivine is altered to a green pleochroic mineral with the optical properties of iddingsite. The rock is of rather basic character and is rich in the femic minerals and the alkalies. It belongs to the trachydolerites of Rosenbusch.

Specimen 3.—From a dike about 5 feet wide in the bed of West Hound Creek, in sec. 11, T. 15 N., R. 1 E.

This specimen is a dense dark-green rock with abundant large euhedral crystals of pyroxene and some small crystals of feldspar in an aphanitic groundmass. Microscopic examination shows that the rock is porphyritic and contains numerous large crystals of pyroxene, now replaced by calcite and chlorite, and about an equal amount of labradorite in a fine-textured altered groundmass, which consists of minute feldspar laths with nearly parallel extinction, abundant grains of iron ore, and secondary calcite, chlorite, etc. The groundmass probably consisted originally in the main of alkali feldspar, augite, iron ore, and glass. The rock is very similar to that represented by specimen No. 5, although it is finer textured and more altered. It should probably also be called a trachydolerite.

Specimen 4, soda syenite porphyry.—From the largest dike in the Hound Creek area. The dike occurs in sec. 2, T. 15 N., R. 1 E., and is about 60 feet thick. It forms a prominent ridge wall about three-fourths of a mile long and from 20 to 60 feet high.

This is a dense, rather light gray rock, which has scattered phenocrysts of hornblende and feldspar in a very fine textured groundmass. The thin section shows a few phenocrysts of oligoclase-albite and still fewer of a greenish amphibole in a groundmass which consists largely of stout prisms of albite and oligoclase with some orthoclase and pyroxene and a very little interstitial quartz. Apatite and iron occur as accessory minerals. The amphibole has an extinction angle (approximately $\angle A$) on the cleavage face of 18° and a maximum index of refraction of about 1.70. It is probably an alkali variety. The pyroxene occurs in small grains. It is pale green and faintly pleochroic. The extinction angle could be measured only approximately, but the measurement gave as a maximum value $\angle A = 28^\circ$. The texture of the groundmass might be called coarsely trachytic. The rock is fairly fresh, though the feldspars are dusted with alteration products and large parts of the femic minerals are changed to a brown chloritic material. The texture is rather coarsely porphyritic and the rock is a soda syenite porphyry.

Specimen 6, syenite.—From a sill a few feet thick that crops out in the east bank of Hound Creek in sec. 19, T. 14 N., R. 1 E.:

This specimen is a rather light green fine even-grained rock. It consists largely of orthoclase, but there is considerable altered augite and biotite, some plagioclase, and

a little quartz. Long needles of apatite are prominent; titanite and iron ore are sparingly present; secondary calcite, chlorite, and uraltite are rather abundant. The plagioclase occurs as the core of the orthoclase crystals. The orthoclase is probably a variety rich in soda, as it has a maximum index of refraction of about 1.53. The texture is hypidiomorphic granular and the composition is that of a syenite.

STRUCTURE.

MAJOR FEATURES.

The availability and extent of coal in any field are directly related to the structure. Since the period when the coal-bearing beds were deposited in this region there has been, first, the deposition of several hundred feet of Upper Cretaceous strata, then an epoch of mountain building which resulted in the uplift of the Little Belt and Big Belt mountains and elevated the area above the sea. During or after this epoch intrusions of igneous rocks occurred, and possibly at the same time the faulting and folding of the Hound Creek district was begun. Then followed the degradation of the land to the present surface. All these factors have contributed to produce the present structure of the rocks.

The area considered in this report lies between the north ends of the Big Belt and Little Belt mountains and extends from the flanks of the latter range on the east to the base of the former on the west. The strata lie in a low monocline dipping away from the mountains toward the northwest. This monocline is broken in many places by faults and folds, and though the beds dip locally in almost any direction, the average dip is about 4° or 5° NW., but as the plains country is approached the dips flatten.

The Little Belt Mountains constitute a broad, flat-topped anticline of sedimentary rocks cut up into smaller ridges by subsequent erosion. The steeply dipping sides of this anticline form the slopes of the mountain range, and the more gently dipping beds extending out from it toward the west are the bench lands of the Hound Creek district. There are few faults and local folds associated with the Little Belt Mountains anticline.

From the complexity of the structure along the northeast border of the Big Belt Mountains, where faults are very numerous and where igneous rocks have in many places been thrust up through Paleozoic beds, the formation of these mountains was apparently accompanied by more complex disturbances than in the Little Belt Mountains. The beds of the Hound Creek area, though more faulted, also dip away from the Big Belt Mountains. The number and magnitude of faults increase toward the mountains, which suggests that the faults are directly related to the disturbances connected with mountain building.

FOLDS.

In the Hound Creek district there are several small folds of the strata which are parallel to one another and to the faults of the field, and which strike northwest. Perhaps the most prominent anticline is in the extreme southwestern part of the district. Here the folding was so sharp that a thrust fault resulted, in which the beds on each side dip away from the fault zone. Although the fault line was not actually observed, it is known to be present because the Kootenai formation and the Colorado shale are almost in contact with the Quadrant formation. In the valley of Elk Creek, in sec. 34, T. 14 N., R. 1 E., the anticline is less sharp and seems to pitch and die out, but from this place eastward the beds are covered, so that it was impossible to decipher the structure in detail. North of the fault above referred to and forming a rather broad valley is a syncline, the axis of which enters this district in the SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 25, T. 14 N., R. 1 E., and extends westward through secs. 25 and 26, where it bends toward the northwest and trends in a nearly direct line to the boundary of the district near the SW. $\frac{1}{4}$ sec. 6, T. 14 N., R. 1 E. At the east side of the district this syncline is very narrow and pitches westward. It becomes broader toward the west until it is about 4 miles across at the west side of the field. The greater part of the surface rock included in this syncline is the Colorado shale, which is bordered on either side by the Kootenai. The beds dip irregularly toward the axis of the syncline at angles varying from a very slight amount to 50° or 60° .

At the east edge of the district, in the NE. $\frac{1}{4}$ sec. 34, T. 16 N., R. 3 E., an anticline is exposed where it crosses a north-south ridge. The fold could not be traced beyond the ridge, but rather strong local dips toward the north were observed in the NW. $\frac{1}{4}$ sec. 34, and the beds to the south, in sec. 5, T. 15 N., R. 3 E., dip 15° – 35° S., so that the broad valley of Clark Creek in secs. 28, 29, 32, and 33 is believed to be in part at least an anticlinal valley.

In secs. 11 and 12, T. 16 N., R. 1 E., there is an anticline which seems to replace a fault from the southeast. This anticline is observable for less than a mile in a northwesterly direction. It brings the Kootenai formation to the surface in an outcrop which is entirely surrounded by the Colorado shale in such a way that an elongated dome is suggested. The exposures are so incomplete that the structure could not be determined with certainty.

A syncline on the south side of the fault in T. 16 N., R. 2 E., extends from the SE. $\frac{1}{4}$ sec. 35 to Hound Creek in sec. 27. It pitches northwestward parallel to the fault and not more than a mile distant. The dips on the two sides of the syncline range from nearly horizontal to 20° or 30° .

FAULTS.

The Hound Creek district is much faulted, particularly in the southwestern part. The principal faults are of the overthrust type, normal faults being confined principally to those of lesser throw. Faulting has brought the hard rocks of the Quadrant and Ellis formations to the surface in places, and from their greater resistance to weathering escarpments have been formed.

Carter ranch fault.—A fault enters T. 16 N., R. 2 E., in sec. 36 and leaves it in sec. 7. It crosses Hound Creek near Carter ranch, in sec. 21, and for this reason is termed the Carter ranch fault. The fault curves to the west and dies out near the township line, on the west side of sec. 7. This fault displaces the beds about 700 feet at the place of its maximum throw, in secs. 26 and 27, where the Quadrant is brought up against the Kootenai along the south side of the fault line. Partly on account of the westerly dip and partly because of the difference in amount of throw, which has produced a stronger westerly dip on the south side, the fault has offset the Kootenai-Colorado contact about 3 miles. On the north side of the fault this contact is in the valley wall on the west side of Hound Creek in sec. 21, T. 16 N., R. 2 E., but on the south side it is in sec. 12, T. 16 N., R. 1 E., over 4 miles farther west. The strata dip in general away from the fault at angles of 70° to 90° on the upthrown side but less steeply on the downthrown side. This fault, like the other great faults farther southwest, is probably of the thrust type, although the evidence along the fault plane is not conclusive. However, as it is parallel to others which are known to be thrusts, and as it also seems to have resulted from a broken fold, it is believed to be a thrust fault.

Green ranch faults.—Two faults cross East Fork of Hound Creek just above the Green ranch. They are best exposed in the valley walls, where they are about a quarter of a mile apart, but they converge on the hill about half a mile northwest of Hound Creek. They continue roughly parallel in a southeasterly direction. The northern one dies out in Crooked Creek valley near the west side of sec. 12, T. 14 N., R. 1 E., and the other extends to the southeast border of the district in sec. 19, T. 14 N., R. 2 E. Although the fault line is not exposed farther northwest than the top of the hill near the township line, the fault continues in this direction as much as 2 miles and forms the escarpment south of Adel. These are thrust faults, in which the fault plane dips southwest, toward the upthrow. In the hillside on the north bank of Hound Creek limestone of the Quadrant formation is thrust up over sandstone of the Colorado. The succession of beds as exposed here is Kootenai and Colorado below (downstream from the east fault); Quadrant, Ellis, Morrison (?),

and Kootenai between the two faults; and Quadrant, Ellis, Morrison(?), Kootenai, and Colorado west of the upper fault. Between the two faults Quadrant, Ellis, Morrison(?), and Kootenai occur in narrow zones and dip southwest at an angle of about 40° . The maximum displacement of beds by these faults occurs in sec. 3, T. 14 N., R. 1 E., and is probably about 1,000 feet. The offset of the Kootenai-Colorado contact is nearly 4 miles from sec. 3, T. 14 N., R. 1 E., to sec. 30, T. 15 N., R. 1 E. The dips on both sides of these faults are southwest and range from 5° or 6° to 40° or 50° .

Crooked Creek fault.—The Crooked Creek fault is best developed in sec. 24, T. 14 N., R. 1 E. It enters the Hound Creek area at the east side of the section on Crooked Creek, strikes in a northwesterly direction, and dies out gradually within about 2 miles. It is apparently a thrust fault, as the Quadrant-Ellis contact on its south side is brought up against the Kootenai. The maximum throw is about 400 feet, and the base of the Kootenai formation is offset about 2 miles.

Faults near Elk Creek.—Fault near the Northern Pacific coal prospect, in sec. 15, strikes in a northwesterly direction. For about half a mile on each side of Elk Creek this fault is very prominent, but beyond this stretch it can not be made out. The beds on the north side of the break dip at a low angle southward into the fault; those on the south side dip 40° – 74° S. The fault plane dips at a high angle to the south. The fault is normal and has a downthrow of about 150 feet to the south, which brings the base of the Morrison(?) against the Quadrant.

Near the head of Elk Creek, in secs. 3 and 4, T. 13 N., R. 1 E., are two parallel faults about a quarter of a mile apart. These are both thrust faults which strike in an easterly direction and dip about 60° S. The fault planes are parallel to the bedding planes and the throw on both planes has brought the Quadrant against the Kootenai. These faults extend about half a mile on each side of Elk Creek, being terminated by an igneous mass on the east and merging into more complex faults on the west.

ECONOMIC GEOLOGY.

RESOURCES.

Coal is present locally in the area under discussion, and there is an abundance of sandstone in the Ellis, Kootenai, and Colorado formations and of limestone in the Quadrant and Madison formations, which might be used for building. It is probable that calcareous shale, with the proper proportions of lime and clay to make Portland cement, could be found in the Quadrant. No metallic minerals are known to occur in the Hound Creek district.

THE COAL.**OCCURRENCE.**

Coal occurs locally in this district in a zone about 60 feet above the base of the Kootenai formation in close association with a thick bed of sandstone. The work of the United States Geological Survey in the Great Falls coal field in 1906 and in the Lewistown field in 1907 has shown that coal does not occur regularly throughout the region, the coal zone being in places either occupied by a very thin seam embedded in carbonaceous shale or entirely replaced by shale. This irregularity was found also in the Hound Creek district.

Just north of the Hound Creek district, on both sides of Hound Creek, in T. 17 N., R. 2 E., and along McMullin Creek, in T. 17 N., R. 3 E., there is a coal bed averaging about 4 feet in thickness, and two mines are in operation in sec. 24, T. 17 N., R. 2 E., where about 2,000 tons is taken out annually for local consumption. These mines are described by Fisher¹ under the heading "Smith River mines." It is believed that the coal pinches out within a short distance south of these mines, for in a prospect along McMullin Creek, in the SW. $\frac{1}{4}$ sec. 31, T. 17 N., R. 3 E., the coal changes from a bed 3 feet thick at the entrance of the prospect to a thin film in the face of the entry, and in the NW. $\frac{1}{4}$ sec. 6, T. 16 N., R. 3 E., the sandstone immediately above the coal zone shows prominent cross-bedding, giving evidence of shore conditions and strong currents. Only carbonaceous shale could be found at the coal horizon along the west side of Hound Creek in T. 15 N., R. 2 E., and in the southern part of T. 16 N., R. 2 E. The only coal observed more than 6 or 8 inches in thickness occurs in two prospects on Elk Creek.

In the area along Elk Creek the Northern Pacific Railway Co. prospected for coal in 1905, but most of the openings have since caved. That this company found no coal which it considered of economic value is indicated by the fact that the land was offered for sale as agricultural land. There are two prospects which were open at the time the field examination was made, however, one in sec. 15, T. 14 N., R. 1 E., and the other in sec. 3, T. 13 N., R. 1 E. The one in sec. 15 was open 40 feet down a dip of 47° S. The following section was measured here:

Section of coal bed in sec. 15, T. 14 N., R. 1 E.

	Ft.	in.
Shale.....	2	4
Coal, fair quality.....	1	9
Shale, carbonaceous.....	2	8
Coal, very impure.....	6	10
Shale, carbonaceous.....		
	13	7

¹ Fisher, C. A., op. cit., pp. 66-67.

East of this prospect the coal bed approaches a fault and increases in dip until an angle of 74° is reached. Then for a short distance the coal bed is cut out, but it reappears and the heavy sandstone above it is traceable around the synclinal trough in sec. 25.

Near the head of Elk Creek, in sec. 3, T. 13 N., R. 1 E., there are two prospects, one on each side of the stream. The one on the west side was full of water at the time of visit and so could not be entered, but the one on the east side was open for a distance of about 60 feet, and the coal was found to be 7 feet 6 inches thick with roof and floor not exposed. The coal is much crushed, however, and dips 61° S. The coal undoubtedly terminates on the east at the igneous mass in sec. 2. West of the prospect the structure is very complex and the rocks are largely covered to the foot of a mesa of igneous rock. Whether the coal is present south and west of this place the writer was not able to learn, but the heavy sandstone that comes near the coal horizon was observed at two or three places high in the hills.

CHARACTER.

No samples for analysis were taken in the Hound Creek district, because only weathered coal could be obtained. However, a sample was taken by the writer from the Gibson mine, on Hound Creek, just north of the area, and according to the Pishel mortar test¹ some of it possesses coking properties but other pieces do not.

The mortar test was worked out by Pishel while engaged in the study of the physical properties of coal in the United States Geological Survey. He found that coals known to possess coking qualities adhered to the sides of the mortar and to the pestle on being pulverized, whereas noncoking coals adhered very slightly or not at all. Sufficient experiments have not yet been made to prove that this test is absolutely reliable, yet it is probably more certain than the ordinary field method of testing in a pit.

Fisher² states that "Certain benches of the coal of the Great Falls field possess coking properties. Formerly a number of coke ovens were operated by the Anaconda Copper Mining Co. at Belt. The separation of coking from noncoking coal, however, was too expensive to render the work profitable, and they were abandoned."

As the sample above referred to was obtained in the ordinary manner, by making a cut entirely across the bed, the fact that some pieces of this sample show coking properties and other pieces do not would indicate that the coal bed here, as in the Belt district, contains benches which might be coked. Samples collected by Fisher³ in 1906 from

¹ Pishel, M. A., A practical test for coking coals: Econ. Geology, vol. 3, No. 4, pp. 265-275, June-July, 1908.

² Fisher, C. A., op. cit., pp. 80-81.

³ Idem, p. 80.

mines near the mouth of Hound Creek show the coal to average about 10,500 British thermal units, and from the analysis and physical properties he states that the coal is medium-grade bituminous.

FUTURE DEVELOPMENT.

It is highly improbable that the Hound Creek district will ever be an important coal-mining center because the coal probably does not occur in sufficient quantity and is too impure to justify the establishment of a plant to mine coal for shipment, even if transportation facilities were available. At present the nearest railroad is the Helena-Great Falls branch of the Great Northern Railway, which is about 20 miles to the northwest. The known amount of coal will certainly not warrant the extension of the Great Northern Railway into the Hound Creek district on that account alone, and the other resources of the district are too meager to bring about in the near future a betterment of transportation facilities. Development of the coal, therefore, will probably be dependent on purely local demand.



DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 641—I

ANTICLINES IN CENTRAL WYOMING

BY

C. J. HARES

Contributions to economic geology, 1916, Part II
(Pages 233-279)

Published December 16, 1916



WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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ANTICLINES IN CENTRAL WYOMING.

By C. J. HARES.

INTRODUCTION.

The area herein designated central Wyoming, as shown in figure 16, covers nearly 5,000 square miles in Natrona and Fremont counties west of Casper and southeast of Lander, and includes no proved oil

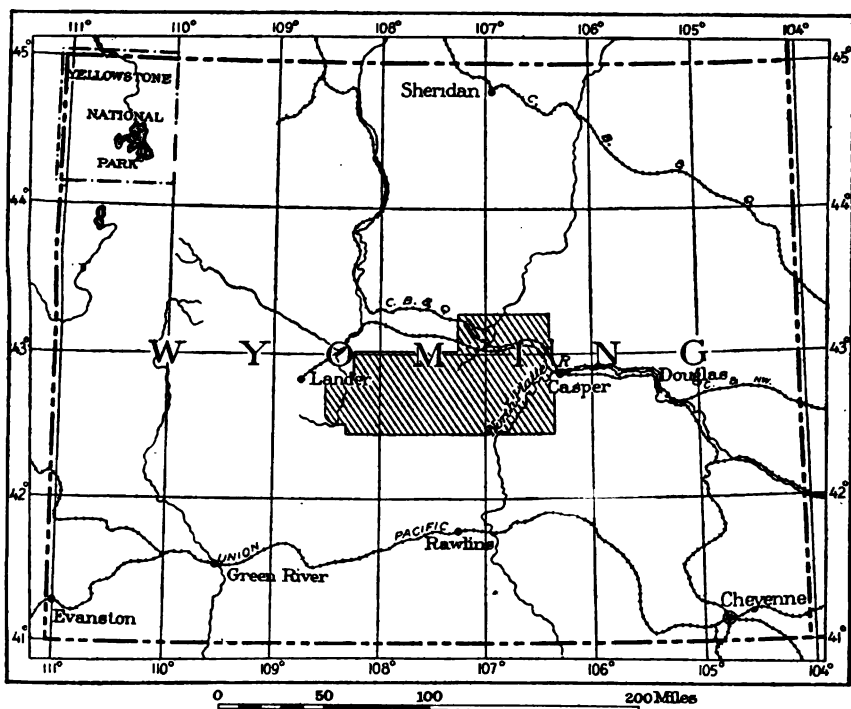


FIGURE 16.—Index map showing position of area designated central Wyoming.

fields. This area was investigated primarily to ascertain the possibilities of oil, and as a result it was found that the Carboniferous and Cretaceous formations which produce oil in other Rocky Mountain fields are well developed in central Wyoming and in places the oil seeps from them, but that in only a few places are these formations covered

by impervious shale and within reach of the drill in folds favorable for the accumulation of oil and gas. The favorable folds are the Pine dome, the Oil Mountain anticline, the anticlines between Poison Spider and South Casper creeks, and the Emigrant Gap, Iron Creek, North Casper Creek, and Bates Hole anticlines, but even these most favorable folds may be barren of oil. The Cretaceous oil sands are below the surface in the Big Sand Draw anticline, in the anticline southwest of Powder River, and in the dome (?) on Wallace Creek, but each one has some disqualifying features. The oil-bearing formation may be too far below the surface to be easily reached by the drill, or the anticline may be incomplete—that is, the axis may pitch in one direction only, allowing any possible oil that the sand may have originally contained to migrate upward along the strata to the surface and to escape, either during the period of erosion prior to the deposition of the flat-lying variegated Tertiary beds that rest on the truncated edges of the folded Cretaceous and Carboniferous formations or during the present erosion period.

The area is in the Wyoming lowlands of the Rocky Mountain division of the United States, and is one of varied character, as it includes mountains, high escarpments, plateaus, badlands, and some large streams, but even though the area lies across the backbone of the Rocky Mountains and extends nearly to the Continental Divide, it is devoid of lofty snow-capped peaks. It is a natural pass over the mountains where the altitudes range from a little over 5,000 to 8,210 feet. This pass was chosen by the pioneers journeying overland to California and other parts of the far West. The Laramie Mountains border it on the southeast, the foothills of the Bighorn Mountains extend into the northeast part, and the Ferris, Pedro, Freezeout, and Seminoe mountains lie to the south. Sheep Mountain, on the western edge of the field, forms a part of the foothills of the Wind River Mountains. Crooks Mountain and Green Mountain are situated along the southern border and the Granite Mountains, in the middle-southern part of the area, are bare rugged granitic masses rising to an altitude of 8,040 feet in Hayden Peak, about 2,000 feet above the Sweetwater Valley. Sweetwater River unites with the North Platte in the Pathfinder reservoir, and the North Platte crosses the extreme southeastern part of the area and flows eastward into the Missouri. Twin Creek, which drains the northwest corner, flows into Little Popo Agie River, a tributary of Wind River. Beaver, Conant, Deer, and Muskrat creeks flow northward into Wind River and eventually into the Missouri by way of Bighorn and Yellowstone rivers. Wallace Creek, an upper tributary of Powder River, flows northeastward and eventually into the Yellowstone. The Rattlesnake Mountains, which rise 8,210 feet above sea level in the middle of the area, with the Sweetwater escarpment, form a part of the divides between these river systems.

The area may be reached from the east by the Chicago & Northwestern and Chicago, Burlington & Quincy railways, which cross the northern part of the area, or from the south by journeying 50 miles overland from Rawlins or other stations on the Union Pacific Railroad. The country is so sparsely settled and the land is so rough that many of the wagon roads are mere trails and usually follow of necessity the easiest route between towns or between some ranch and the nearest town on a railroad. Intricate badlands and other uneven features make travel difficult and haulage slow and unfit the land for agriculture.

Prospectors have been attracted by the indications of oil about the anticlines, but the rough land, the scarcity of permanent streams, and the remote location of good springs and fuel have controlled the location of drilled wells to the extent of preventing the prospecting of some of the more favorable parts of the anticlines for oil or gas. In addition to high freight rates there are excessive charges for teaming overland to the wells, most of which are from 10 to 30 miles from a railroad.

The subbituminous coal beds west of the Pine and Oil mountains, east of the Rattlesnake Mountains, north of the Dutton anticline, east of Alkali Butte, and on Big Sand Draw are available for fuel in these localities, but in the eastern part of the area coal beds are absent and other sources of fuel must be found. In the northeast corner of the area oil is available from the Salt Creek field by a day's haul, and in the eastern part by a similar haul from Casper. Timber is scarce, and most of the trees are scrub pine and cottonwood. The better timber is restricted to the higher mountains.

Prospecting for oil and gas in central Wyoming, because of the surface conditions outlined above, is expensive.

The geologic work upon which this report is based was begun in July, 1913, and completed in the autumn of 1914.

ACKNOWLEDGMENTS.

The writer appreciates the suggestions and criticisms of M. R. Campbell, who had general supervision of the work, and gratefully acknowledges the assistance of his associates in the field, M. W. Ball, Stuart St. Clair, J. B. Reeside, jr., K. C. Heald, and A. C. Collins. Many kindnesses were extended to the party during both field seasons by the ranchers and other persons living in the area, also by the oil companies engaged in prospecting the region.

WATER SUPPLY.

Sweetwater River unites with the North Platte in the great Pathfinder reservoir, which stores water during the flood seasons for irrigation in eastern Wyoming and western Nebraska. These rivers

and most of the creeks near their sources contain running water throughout the year, but the smaller creeks flow only early in the spring or after heavy showers. Even Powder River during the summer goes dry along most of its course, and though Beaver Creek supports trout above Hailey it runs dry farther down. As the precipitation averages only about 10 inches a year and usually falls in heavy showers the area is in the semiarid belt. Throughout the region there are many springs of good water, as well as many in which the water is exceedingly alkaline. The abundance of springs, together with the number of running streams, makes the country locally well watered and admirably adapted to stock raising. There is a large warm spring flowing good water at the head of Horse Creek, in sec. 35, T. 32 N., R. 86 W.; hot water rich in mineral salts issues from the gorge in the banks of North Platte River just above Alcova; and a big spring of excellent water in sec. 15, T. 32 N., R. 81 W., is used to irrigate about 1,000 acres of the Bessemer flats. The Big Sulphur Springs, in sec. 5, T. 38 N., R. 83 W., are locally well known. There is also warm water issuing from the sides of Beaver Gorge, about 4 miles above Hailey, in T. 30 N., R. 97 W. The Warm Springs, near the center of T. 29 N., R. 95 W., and Happy Springs, in the southeast corner of the same township, are valuable. Dams are built by ranchers in the dry valleys to pond the run-off of heavy showers and thus make it available for stock. This practice is followed also by oil companies to obtain water for drilling operations. At times, however, water for drilling must be hauled or piped from some distant creek or spring.

All the deep wells in this area have found artesian water in the sandstones. This fact and the presence of large springs indicate that artesian water may be obtained in many parts of the area where the structural and topographic conditions are favorable.

The Lower Cretaceous conglomerate is the principal water-bearing formation and usually furnishes a strong sulphur water. The sandstones in the other formations generally contain water in less quantity, because they are less continuous and less uniform in thickness and texture.

OBJECT OF THE SURVEY.

The examination of central Wyoming was undertaken to determine whether or not the region contains anticlines or other folds favorable for the accumulation of oil and gas and also the number and occurrence of oil sands. If favorable folds are present, the next important question is whether the oil-bearing sands are sealed below impervious rocks in those folds so as to hold the oil and gas or whether those sands have been exposed by erosion, allowing the oil and gas to escape.

The table facing page 238 illustrates the fact that in most of the Rocky Mountain oil fields the oil seeps and productive sands are confined chiefly to Cretaceous strata. The occurrences outside of the Cretaceous so far discovered have proved of minor economic importance.

The Wall Creek sandstone, the uppermost sandstone member of the Frontier formation, is the main productive sand at Salt Creek and the oil has a gravity of 0.82 to 0.85. Some oil having a specific gravity of 0.909 is obtained at Salt Creek in the Shannon sandstone lentil of the Steele shale, and some is also obtained in the Niobrara.¹ In the Grass Creek field the middle part of the Frontier formation bears oil, and along Shoshone River gas is obtained from the upper part of the Cloverly and some oil from sandstones in the Thermopolis and Mowry² shales but most of the oil (specific gravity 0.833) comes from a sandstone in the lower part of the Thermopolis shale.

At Greybull,³ in the Peay anticline, gas and a light-gravity oil occur in the Kimball sand of the Mowry shale and in the top of the Cloverly. In the Torchlight dome at Basin a light oil of 0.7955 gravity occurs in the Peay sand of the Frontier formation, but in the Lamb anticline a heavy oil of 0.889 gravity occurs in the Kimball sand and the Peay sand, and gas occurs commercially in the Peay sand and in traces only in the Torchlight, Muddy, and Kimball sands.⁴

At Elk Basin gas and a light-gravity oil occur in sands (Frontier) of Benton age, and at Byron oil occurs in the Frontier and gas in the Cloverly.

At Spring Valley a light oil of 0.82 gravity occurs most abundantly in the Aspen shale, and to some extent a heavy oil occurs in the Bear River and Frontier formations. The Wasatch produces oil at both Spring Valley and Labarge, but according to Veatch⁵ and Schultz⁶ the Wasatch oil has migrated from the underlying Aspen shale. Sandstone in the Graneros shale at Moorcroft has produced the little oil obtained there,⁷ which has a specific gravity of 0.919.

At Douglas the top of the "Cloverly" (Dakota?) produces some oil, and the sands (Frontier) of Benton age, both oil of gravity 0.843 to 0.93 and gas, but most of the commercial product comes from the

¹ Wegemann, C. H., The Salt Creek oil field, Natrona County, Wyo.: U. S. Geol. Survey Bull. 452, pp. 37-83, 1911.

² Hewett, D. F., The Shoshone River section, Wyo.: U. S. Geol. Survey Bull. 541, pp. 89-113, 1914.

³ Hintze, F. F., Basin and Greybull oil and gas fields: Wyoming State Geologist's Office Bull. 10, p. 45, 1914 [1915].

⁴ Lupton, C. T., Oil and gas near Basin, Big Horn County, Wyo.: U. S. Geol. Survey Bull. 621, pp. 157-190, 1916.

⁵ Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: U. S. Geol. Survey Prof. Paper 56, p. 158, 1907.

⁶ Schults, A. R., The Labarge oil field, central Uinta County, Wyo.: U. S. Geol. Survey Bull. 340, p. 364, 1908.

⁷ Barnett, V. H., The Moorcroft oil field and Big Muddy dome, Wyo.: U. S. Geol. Survey Bull. 581, pp. 83-117, 1914.

White River formation. According to Barnett,¹ however, the gas and oil obtained from the White River has probably been derived from the underlying beds of Benton age or from the "Cloverly" and is secondary in the White River.

At Lander, in the Big Popo Agie field, the oil at the Washakie oil spring and in the Plunkett well and other wells near by in the north end of the anticline is derived from the Mowry shale.² It has a gravity of 0.812. The heavy dark-brown oil (specific gravity 0.9+) comes from the Embar (Pennsylvanian to Lower Triassic) and Chugwater (Triassic) formations.

From this brief summary it is evident that the best oil (specific gravity 0.7955 to 0.856, or 45.98° to 33.5° Baumé) produced in paying quantities in the Wyoming fields is obtained from the Cretaceous rocks, and chiefly from beds of Colorado age, though much comes from beds of Montana age. A small quantity of oil of lower grade (specific gravity 0.9198 to 0.9091, 22.2° to 24° Baumé) comes from the Embar beds.

As the Lander field, in which the only notable quantity of oil comes from the Embar formation, joins on the west the area treated in this report, it seems reasonable to consider carefully any anticline or dome in this area in which that formation is sealed beneath impervious rocks and within reach of the drill. Any anticline or dome where the important oil-bearing formations of the Cretaceous are closed beneath thick beds of shale should be considered still more carefully.

The accumulation of oil and gas in all the productive fields of Wyoming, except Spring Valley and Douglas, is controlled by anticlinal folds. At Spring Valley the oil accumulates in a syncline—the reverse fold of an anticline—probably because the rocks are not saturated with water, a condition which allows the oil by force of gravity to seek the low places in the downfold or syncline.

In central Wyoming the wet porous sands occur between impervious shales. Where oil-bearing formations under such conditions have been folded the anticlines and domes have been found to be the favorable places for the retention of oil and gas, presumably because oil and gas, being lighter than water, are floated and forced to the crests of the anticlines and domes, or at least as far up as the water has any head. If, as is the case in many of the anticlines in central Wyoming, erosion has removed parts of the oil-bearing formations, the oil and gas have had ample chance to escape and there is little possibility of their retention. In such places indications of oil occur as seeps along the outcrop of the sandstone. Wells drilled down the

¹ Barnett, V. H., The Douglas oil and gas field, Converse County, Wyo.: U. S. Geol. Survey Bull. 541, pp. 49-58, 1914.

² Woodruff, E. G., The Lander oil field, Fremont County, Wyo.: U. S. Geol. Survey Bull. 452, pp. 7-36, 1911.

	gas.)
Syst	Salt Creek and Powder River
Terl	
	Fort Union.
Terl	Lance.
	Fox Hills.
	Pierre.
	Parkman.
	Shannon. o
	Niobrara. o.
	Benton.
Cred	Wall Creek.
	Mowry. +
	Dakota(?). +
Cred	Morrison. +.
Jura	Sundance. +
Trias	
Perm	
Perm	

56, 1912.
 field, Converse Co
 and Big Muddy dot
 resources of the cat
 er district, Colo.:
 11, Colo.: U. S. Ge
 E.

dip from such outcrops penetrate these beds and commonly obtain water with a few drops of oil. This was true of the Oil City, the Northwestern, the Dutton "Basin," and the Western States wells. Under these conditions it is clearly evident that anticlines having the oil-bearing sandstones completely sealed beneath impervious beds should be first chosen for prospecting.

The accompanying table summarizes the available information as to the geologic position of the oil and gas bearing beds in the Wyoming and some adjacent fields.

HISTORY OF PROSPECTING.

The presence of oil seeps in this region was first described by Aughey in 1886.¹ Some of these seeps, however, had been known since the days when the first emigrants passed through the region going to Oregon and California. It is reported that Cimineau,² a French trapper, and others sold lubricants to the caravans from the oil spring in sec. 28, T. 33 N., R. 82 W., 1 mile south of Poison Spider Creek, near Oil Mountain.

One of the first wells sunk in the area covered by this report was drilled in 1886 on Poison Spider Creek, in sec. 4, T. 32 N., R. 86 W., at Oil City, by the Colorado & Wyoming Land & Oil Co. Under the management of George L. Aggers, of Douglas, Wyo., this well was put down to a depth of 1,130 feet and at a depth of 500 feet struck 130 feet of sandstone, which carried a little oil and water.³

The two wells drilled by the Wyoming Central Association in the early eighties near the head of Powder River to depths of 700 and 900 feet were water wells with only a slight showing of oil.⁴ It is thought that the first well drilled prior to 1886 near the SW. $\frac{1}{4}$ sec. 34, T. 34 N., R. 88 W., to a depth of nearly 1,000 feet, which obtained a slight amount of oil, gas, and much water, was one of the Wyoming Central Association wells.⁵ The Northwestern Oil Co.'s well, which according to Knight⁶ was drilled about the same time and a short distance northwest of the Wyoming Central Association wells to a depth of about 500 feet, struck no appreciable quantity of oil. When visited in 1915 a well near the west quarter corner of sec. 20, T. 33 N., R. 87 W., was giving off a small quantity of gas and a few drops of oil. There was only enough dark, thick, asphaltic oil on the water which rose to the top of the casing to furnish a small sample. No data seem to be available concerning the Moffat well, on Lovett Creek.

¹ Aughey, Samuel, Wyoming Territorial Geologist Ann. Rept., 1886, pp. 113-187.

² See U. S. Geol. Survey Bull. 612, p. 62, 1915.

³ Ricketts, L. D., Wyoming Territorial Geologist Ann. Rept., 1888, pp. 22-36.

⁴ Idem, p. 35.

⁵ Aughey, Samuel, op. cit. Knight, W. C., Wyoming Univ. School of Mines, Petroleum series, Bull. 4, p. 28, map, 1901.

⁶ Knight, W. C., Idem, pp. 21-26.

Nearly contemporaneous with the sinking of the Northwestern well was the drilling of the Guthery well, in sec. 18, T. 33 N., R. 82 W., on Poison Spider Creek. This well was sunk to a depth of about 1,000 feet, and a flow of strong sulphur water was encountered, presumably in the Lower Cretaceous conglomerate. It is reported that some oil was found, but that the quantity was so insignificant that oil was hauled from the wells at Salt Creek and the place "salted." At the time of visit a small stream of water surcharged with hydrogen sulphide gas flowed from the casing, but there was no indication of oil.

It is said that a shallow well was drilled farther down Poison Spider Creek, just above the Goose Egg ranch, and that the tools were purposely lost in it.

The well near North Platte River, 2 miles above Alcova, struck water but no oil. Its location is in the syncline between the monoclinal fold to the west and the Alcova or Hot Springs arch to the east.

Scattered throughout the area are assessment pits of the oil-prospecting days of the eighties, and it is almost impossible to ride over the area for any considerable length of time without seeing some of them. It is reported that a small quantity of oil was collected in some of these pits near the Horse Creek dome, in secs. 26, 27, and 34, T. 32 N., R. 86 W. At the oil spring near the north end of Oil Mountain there are two pits. The western one of these, which was dug to a depth of 10 feet or so, has nearly filled up by caving and when visited contained about 3 feet of water covered with a thin scum of thick, dark oil. It is from this place that a small quantity of oil was supplied to the travelers who trailed through the region in the days of 1849.

After the era of assessment pits and shallow wells very little prospecting was done until the development of the Salt Creek and Bighorn Basin oil fields revived interest in oil through the area. The first operation was the sinking of a test well by the Midwest Oil Co. on the Castle Creek fold, near the east quarter corner of sec. 31, T. 38 N., R. 80 W., to a depth of about 2,000 feet. Some gas was found in the shale above the Wall Creek sand, and from the sand water rose nearly to the top of the casing. A little gas was escaping from the well when it was visited late in the fall of 1914.

A well completed in the summer of 1913 at the north end of the Dutton anticline was started near the contact of the Niobrara and Steele shales, in the NW. $\frac{1}{4}$ sec. 34, T. 34 N., R. 90 W. It was drilled to a depth of about 1,060 feet, and when visited it was giving off gas in small quantities, and thick, dark oil stood on the water about 20 feet below the top of the casing.

In the summer of 1913 the Ohio Oil Co. drilled two holes, one on Poison Spider Creek in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 18, T. 33 N., R. 82 W., and the other in the NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 2, T. 33 N., R. 95 W., near

Alkali Butte in the "Riverton oil field." In the well on Poison Spider Creek the Dakota sandstone at a depth of 641 feet contained some black oil. The Lower Cretaceous conglomerate at 785 feet carried water and a little oil, and the Morrison formation showed signs of oil. The well was sunk to a depth of 2,855 feet, and the last 15 feet was in the Tensleep sandstone, which contained artesian water. The other well, near Alkali Butte, encountered no water anywhere in the 2,945-foot hole, which was probably entirely in the Steele shale. A trace of gas and oil was obtained in a 7-foot bed of soft sand at a depth of 177 feet.

The Holmes well, in sec. 3, T. 36 N., R. 82 W., was the first one located on the North Casper Creek anticline. This well, which is about 500 feet west of the contact of the Niobrara and Steele shales, is 2 miles west of the axis of the anticline and was drilled to a depth of 1,170 feet. It penetrated 15 feet into the Wall Creek sand, from which water rose within 100 feet of the top of the casing.

The Fitzhugh well, $1\frac{1}{2}$ miles north of the Holmes well, was started June 19 and finished August 24, 1913. It is near the west quarter corner of sec. 26, T. 37 N., R. 82 W., about 800 feet east of the upper contact of the Niobrara shale. The locator in the selection of this site seems not to have considered duly the record of the Holmes well and the form of the anticline, otherwise his location would not have been so near the contact of the Steele and Niobrara shales, a position on nearly the same structure contour as that of the Holmes well. The two logs are similar. In the Fitzhugh well water was struck in the Wall Creek sand at a depth of 1,000 feet, and the well was abandoned at 1,642 feet.

The Monongahela Oil Co. commenced operations in July, 1913, in the SE. $\frac{1}{4}$ sec. 9, T. 33 N., R. 81 W., just west of Twelvemile Spring, in the Emigrant Gap anticline. At a depth of 240 feet a flow of sulphur water was struck in the Lower Cretaceous conglomerate. This is the only well so far drilled near the axis of the anticline. The dry holes on Casper Creek, in Tps. 33 and 34 N., R. 80 W., are far down the east flank.

The Western States Oil Co.'s well, started in the summer of 1913 near the center of T. 33 N., R. 94 W., in the so-called Riverton oil field, is in the syncline between the Conant Creek and Alkali Butte anticlines. The location is on the Steele shale, and, according to reports, the Wall Creek sand, at a depth of 1,300 feet, showed some trace of oil. The well was not completed at the time of the field examination.

The Franco-American well, in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 16, T. 34 N., R. 87 W., is on the Wallace Creek dome (?). This well was put down about 600 feet during the summer of 1913, but was idle when the area was mapped. Later it was sunk to a depth of more than 2,000 feet,

probably entirely in the Fort Union and Lance formations, but encountered no oil.

The Toltec Oil Co. late in the fall of 1913 put down a well in sec. 11, T. 37 N., R. 85 W., on the Cottonwood Creek anticline, at the south end of the Bighorn Mountains. It was free from water down to a depth of 915 feet, except small quantities at 125 and 458 feet, but at 915 feet warm and highly charged sulphur water, presumably from the Lower Cretaceous conglomerate, flowed in large quantities over the top of the casing. The well was abandoned at a depth of 990 feet without obtaining oil.

In September and October, 1914, William M. Fitzhugh and his associates drilled a 1,975-foot dry hole in the NW. $\frac{1}{4}$ sec. 36, T. 37 N., R. 82 W., on the North Casper Creek anticline. They struck water in the Wall Creek sand at a depth of 440 feet and in the Peay sand at 1,045 feet, but the Dakota (?) sandstone at 1,675 feet was dry. The Lower Cretaceous conglomerate at a depth of 1,769 feet and also the Morrison formation carried water. Free carbon, bitumen, paraffin, and some carbonic gas were found in dark-blue shale at 1,560 and 1,679 feet. This well is located near the axis of the anticline about 2 miles north of its crest and with the other wells drilled near by has shown that the pool of oil or gas, if any exists in this anticline, is not greater than $1\frac{1}{2}$ by $4\frac{1}{2}$ miles in extent, which is almost the size of the Salt Creek field.

The Casper Oil Co. in the fall of 1915 started a well in sec. 28, T. 38 N., R. 81 W., about a mile below the 33 Mile ranch on Castle Creek. This well was dry for 1,900 feet.

Aside from these wells, drilled by standard outfits, numerous assessment holes have been put down with Star rigs, none of which have attained sufficient depth to be of value. The prospecting of this sort that has been done along the eastern flank of the Rattlesnake Mountains is a good example of waste of time and money.

OIL-BEARING FORMATIONS.

Many of the formations in this field, from the Cambrian to the Oligocene, contain sandstone members or strata, but only those which contain traces of oil or produce oil and gas in this or near-by fields will be described. The formations may be seen in the different anticlines of the field, and they will be taken up in stratigraphic order, the lowest one first, as shown in the columnar section on Plate XXIII. That some of the shales contain oil pools is not considered probable, although it is recognized that oil may be present in shale here, as it is in some other Rocky Mountain fields.

Cambrian and pre-Cambrian formations.—The Cambrian and pre-Cambrian beds, according to oral reports, are saturated with oil near Copper Mountain, on the south side of the Owl Creek Mountains, near T. 39 N., R. 92 W., about 40 miles northwest of the Rattlesnake

Mountains. The Wind River formation (Eocene), which overlies the Cambrian at this locality, is also said to show traces of oil. The locality was not examined, but the information is considered reliable. No indications of oil, however, were observed in the Cambrian or pre-Cambrian in the area covered by this paper.¹

Tensleep sandstone.—The Tensleep sandstone, of Pennsylvanian age, is the lowest formation which shows signs of oil in this field. It is approximately 200 feet thick in the Rattlesnake Mountains. An exposure of a few square rods in the SW. $\frac{1}{4}$ sec. 13, T. 33 N., R. 90 W., in the Dutton anticline, contains some oil, but so far as observed none escapes. At all other localities where the formation was examined it is barren. The rock is a medium-grained, highly cross-bedded, firmly cemented quartz sandstone, which is of sufficiently open texture to allow the free circulation of water, as shown by the Ohio well, on Poison Spider Creek.

Embar formation.—No indications of oil were seen in the Embar formation (Pennsylvanian, Permian, and Triassic), but in the Lander field,² which adjoins this area on the northwest, it is one of the main oil-producing formations. The Embar overlies the Tensleep sandstone and is composed of 225 feet or more of light-gray fossiliferous limestone, shale, chert, and beds of phosphate. It is typically developed in the western part of the area, where it is equivalent to the Park City and Dinwoody formations, but in the eastern part it is of an entirely different character, consisting mostly of red shale with some limestone, fossiliferous red and gray chert, and gypsum. The Embar in this field contains no thick beds of sandstone. It was reported that the well of the Pine Dome Oil Co. obtained its flow of gas from the Embar, but it is fully as probable that the gas came from the Tensleep sandstone.

Chugwater, Sundance, and Morrison formations.—Along the east flank of the Rattlesnake Mountains north of Garfield Peak there are places where the sandstones in the upper (Triassic) part of the Chugwater, the Sundance (Jurassic), and especially the Morrison (Cretaceous?) formations show signs of oil. Oil seeps from the Sundance and Morrison formations in the unproductive Powder River oil field,³ which is adjacent to this field on the north. These formations contain thin and thick sandstones that in favorable folds would serve as reservoirs for oil. The formations present their usual characteristics. The Chugwater consists essentially of 1,000 feet of brick-red unfossiliferous sandy micaceous shale, thin-bedded sandstone,

¹ Since this was written the indications of oil in this locality have been described as petroleum in granite by L. W. Trumbull (Wyoming State Geologist's Office, Sci. ser., Bull. 1, pp. 4-7, 1916).

² Woodruff, E. G., The Lander oil field: U. S. Geol. Survey Bull. 452, p. 27, 1911. Jamison, C. E., Geology and mineral resources of a portion of Fremont County, Wyo.: Wyoming Geol. Survey Bull. 2, pp. 33-34, 1911.

³ Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, p. 71, 1912.

and gypsum. A thin limestone occurs near the top in the eastern part of the field, but in the western part this same limestone is near the middle of the formation. The Sundance consists of about 300 feet of marine olive-green shale and highly fossiliferous gray limestone. The Morrison consists essentially of 250 feet of fresh-water variegated shale and sandstone.

Lower Cretaceous conglomerate.—The next higher oil-bearing formation is the conglomerate assigned to the Lower Cretaceous. This is the lower part of the "Dakota" formation mentioned by Knight¹ as being the most promising oil-bearing formation of the field. It is the basal conglomeratic sandstone of the Cloverly formation of the Bighorn Mountains, the lower member of the Cloverly formation of the Basin and Greybull oil and gas fields,² and the Dakota (?) of the Salt Creek field.³ It is identical with the conglomerate described as of Lower Cretaceous age (?) in the Lander field.⁴ This formation contains dark-colored, well-rounded chert pebbles, commonly about the size of small marbles but reaching a maximum diameter of 1½ inches, firmly cemented. Usually the cement is silica, but in some places it is lime. The coarse basal conglomerate that constitutes the lower half of the formation grades upward into a slightly conglomeratic sandstone and the whole attains a thickness of about 60 feet. It varies little from this thickness throughout the eastern part of the area, though in the Conant Creek anticline it is only 8 feet thick. The formation where upturned forms small hogbacks, a feature which, with the lithologic character, makes its identification easy.

Though the conglomerate is mentioned by Knight⁵ as showing traces of oil in the Dutton "anticline," none were noticed in it there or in the other exposures of the conglomerate, except along the Rattlesnake Mountains. It is probably the source of the oil at the seep in sec. 28, T. 33 N., R. 82 W., at the north end of Oil Mountain. Small quantities of dark, thick oil ooze from it near the Lew Smith Spring, at the head of Horse Creek, in sec. 26, T. 32 N., R. 86 W., on the southwest side of the Rattlesnake Mountains. A few sections of land have been patented as oil placer land about 2 miles south of Oil City because dark asphaltic oil seeps from the conglomerate beds in that locality. Northwest of Oil City and south of Garfield Peak the conglomerate contains little if any oil, but in places on Wallace Creek and on the small creeks near by it is saturated with dark asphaltic oil. The light volatile parts have evaporated from the oil

¹ Knight, W. C., Wyoming Univ. School of Mines, Petroleum ser., Bull. 4, pp. 17-19, 1901.

² Hintze, F. F., Jr., The Basin and Greybull oil and gas fields, Big Horn County, Wyo.: Wyoming State Geologist's Office Bull. 10, pp. 16-17, 1914.

³ Wegemann, C. H., The Salt Creek oil field, Natrona County, Wyo.: U. S. Geol. Survey Bull. 452, p. 44, 1911.

⁴ Woodruff, E. G., The Lander oil field, Fremont County, Wyo.: U. S. Geol. Survey Bull. 452, pp. 18-19, 1911.

⁵ Knight, W. C., op. cit., pp. 17-19.

that seeps here, and the heavy dark residue, mixed with soil and dead vegetation, has accumulated on the creek bottoms to a thickness of a foot or more and covers many square rods. This deposit is used locally for fuel, chiefly for engines drilling prospect holes. Strong sulphur water was found in the conglomerate in the Ohio well, on Poison Spider Creek, and in the Guthery, Monongahela, and Toltec wells, and similar water issues from the conglomerate in sec. 15, T. 33 N., R. 81 W. The Ohio and Guthery wells struck traces of oil in the conglomerate.

Dakota sandstone.—Directly below the Thermopolis shale and from 100 to 350 feet above the Lower Cretaceous conglomerate is a fine-grained brown to gray quartzitic sandstone, ranging in thickness from a few inches to a maximum of 60 feet, as observed at the south end of the Emigrant Gap anticline. This sandstone is considered the same as the Dakota of the Lander country.¹ It is the upper member of the Cloverly formation of some authors, but is here referred to the Dakota (Upper Cretaceous). It may correspond to the Greybull sand of the Bighorn Basin.² This sandstone contains no oil at the south end of the Rattlesnake Mountains or near Garfield Peak, but at numerous places on Wallace Creek and the creeks to the north it is saturated with dark asphaltic oil and, with the Lower Cretaceous conglomerate, furnishes the asphaltum found in that district. The Dakota shows no trace of oil throughout the rest of the field. This sandstone is so variable in thickness and so unfavorably situated in most of the anticlines that it is considered unimportant as a reservoir for oil unless it may be in the same anticlines as those mentioned in connection with the Lower Cretaceous conglomerate.

Mowry shale.—From 100 to 300 feet above the Dakota sandstone is the Mowry shale, of Upper Cretaceous age, a hard, fissile dark shale, weathering white, which contains abundant fish scales, vertebræ, and fins, but in which no complete skeletons have been found. The Mowry shale, which forms pronounced pine-bearing ridges in most of the anticlines, is normally about 300 feet thick and is an exceptionally good key rock. It is in most localities immediately overlain by a bed of bentonite. No traces of oil were seen oozing from this formation, but it produces oil in the Bighorn Basin,³ at Lander,⁴ and at Spring Valley⁴ and is the probable source of the oil

¹ Woodruff, E. G., op. cit., pp. 18-19.

² Lupton, C. T., Oil and gas near Basin, Big Horn County, Wyo.: U. S. Geol. Survey Bull. 621, pp. 157-190, 1916.

³ Woodruff, E. G., The Lander oil field, Fremont County, Wyo.: U. S. Geol. Survey Bull. 452, p. 27 1911.

⁴ Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: U. S. Geol. Survey Prof. Paper 56, p. 158, 1907.

in the Wasatch formation at Labarge.¹ Oil is reported to occur in the Mowry shale in the unproductive Powder River field.²

One of two samples of the Mowry shale tested by distillation yielded about 2 gallons of oil to the ton and the other a mere trace. The latter contained the greater quantity of fish remains. The tests were made in order to throw light on the possible origin of the Wyoming oil, but the results were unsatisfactory.

Frontier formation.—The Mowry shale is overlain by shale and sandstone that are referred to the Frontier formation, of Upper Cretaceous age. The sandstones, of which there are three distinct divisions corresponding in ascending order to the Peay, an intermediate sand, and the Wall Creek, are of medium to fine grain, gray, somewhat massively bedded, and from 20 to 200 feet thick. The formation attains a maximum thickness of 1,000 feet. The intervening shale, which makes up more than half of the formation, is dark and sandy. The lowest sandstone member, corresponding to the Peay, is persistent and characterized by large brown concretions, especially in the Emigrant Gap and Oil Mountain anticlines and the Pine dome. The middle sandstone is commonly characterized by small black chert pebbles about the size of peas, which usually distinguish it from the other two sandstones, though in a few places the Wall Creek contains similar pebbles. The upper or Wall Creek sand is the main productive oil sand in the Salt Creek field, 25 miles northeast of the North Casper Creek anticline,³ but the Peay and Torchlight are important producing sands in the Bighorn Basin.⁴ The Wall Creek sandstone may correspond to the Torchlight, as shown by Hintze, for it is stratigraphically at about the same position.

Thick, black oil oozes from the sandstones of the Frontier in the Alkali Butte anticline, and traces of oil were found in them along the Rattlesnake Mountains.

Teapot sandstone member of the Mesaverde formation.—The highest Cretaceous sand in which oil was observed is the Teapot sandstone member of the Mesaverde formation (Upper Cretaceous), a medium-textured white sandstone from 90 to 200 feet thick. This sandstone has a wide distribution in Wyoming and is the upper part of the Mesaverde. It is spoken of as the "sandstone forming Little Pine

¹ Schultz, A. R., The Labarge oil field, central Uinta County, Wyo.: U. S. Geol. Survey Bull. 340, pp. 367-371, 1908. Trumbull, L. W., Prospective oil fields at Upton, Buck Creek, Rattlesnake Mountains, and Labarge: Wyoming State Geologist's Office Bull. 5, pp. 14-16, 1913.

² Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, p. 71, 1912.

³ Wegemann, C. H., The Salt Creek oil field, Natrona County, Wyo.: U. S. Geol. Survey Bull. 453 pp. 71-75, 1911.

⁴ Washburne, C. W., Gas fields of the Bighorn Basin, Wyo.: U. S. Geol. Survey Bull. 340, pp. 348-363, 1908. Hintze, F. F., Jr., The Basin and Greybull oil and gas fields, Big Horn County, Wyo.: Wyoming State Geologist's Office Bull. 10, pp. 41-47, 1914. Hewett, D. F., The Shoshone River section, Wyo.: U. S. Geol. Survey Bull. 541, p. 66, 1914.

Ridge" in the Salt Creek field and is the Teapot sandstone near Casper as described by Barnett.¹ It is the prominent sandstone that forms the striking white wall across Tps. 32 and 33 N., Rs. 82 and 83 W., southeast of the F L ranch. This sandstone, forming a low ridge locally known as Phayles Reef near the Marquis ranch, along the east flank of the Rattlesnake Mountains in secs. 4, 5, and 9, T. 33 N., R. 87 W., is highly saturated with oil. This sandstone at Phayles Reef is probably the one conditionally placed by Knight² in the Fox Hills and noted by him as saturated with oil. In prospecting for oil in the dome on Wallace Creek drilling should go at least deep enough to test this sand for oil.

Wind River formation.—The Wind River formation, of Eocene age, consists essentially of soft variegated shale, coarse brown sandstone, arkose, and both fine and coarse conglomerate. These beds are for the most part nearly flat-lying or tilted at very small angles and unconformably overlie all the older formations, including the Cambrian. No oil seeps were noted in the Wind River, but some are mentioned by Knight as occurring west of the Dutton anticline.³ The Wind River is reported to show traces of oil south of the Owl Creek Mountains in T. 39 N., R. 92 W. Oil is obtained in small quantities from beds of nearly the same age at Spring Valley⁴ and Labarge,⁵ in southwestern Wyoming. It is probable that in all these places the oil has escaped from the underlying Cretaceous sands into the overlying beds. As the Wind River in places overlies the upturned Cretaceous oil-bearing sands, it is possible that in some of these places oil may be found in the Wind River, but this seems a remote possibility, and no commercial pools are to be expected.

White River formation.—The White River formation of Oligocene age, is composed essentially of loosely cemented light-colored fine and coarse sand, arkose, and conglomerate. Volcanic material, in the form of pebbles and single grains, is present throughout the formation. Red color is generally absent in the formation, but light green and buff are plentiful and even white rocks are not uncommon. The White River is nearly flat lying and rests unconformably on all formations from the pre-Cambrian granite of the Granite Mountains to the Steele shale and also the Wind River.

Small quantities of oil ooze from beds considered of White River age at the Lew Smith oil spring, in sec. 26, T. 32 N., R. 86 W., in the

¹ Barnett, V. H., Possibilities of oil in the Big Muddy dome, Converse and Natrona counties, Wyo.: U. S. Geol. Survey Bull. 581, pp. 113-114, 1915.

² Knight, W. C., Wyoming Univ. School of Mines, Petroleum ser., Bull. 4, pp. 28-29, 1901.

³ Idem, p. 16.

⁴ Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: U. S. Geol. Survey Prof. Paper 56, pp. 16, 139, 141, 143-144, 151, 1907.

⁵ Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, p. 117, 1914.

Rattlesnake Mountains, but the oil probably comes from the underlying Lower Cretaceous conglomerate or the Dakota sandstone. A little asphaltic material occurs in rhyolitic bombs in the upper part of the White River formation on the Sweetwater escarpment in secs. 10 and 11, T. 32 N., R. 94 W.

It is possible that where this formation lies on the upturned Cretaceous oil sands, as in the area between Alcova and the Rattlesnake Mountains or at the south end of the Rattlesnake Mountains, it may contain small quantities of oil. Commercial pools, it is believed, are not to be expected in the White River in this field. Small pools, however, occur in beds of the same age at Douglas.¹

ANTICLINES² AND OTHER FOLDS.

GENERAL FEATURES.

In comparatively recent geologic time, the outer crust of the earth in all parts of Wyoming, which once lay in great nearly level sheets or beds of shale, sandstone, and limestone, was bent and wrinkled into great and small anticlinal and synclinal folds. These folds or earth waves may be likened to the billows and waves on water or to the wrinkles on merino sheep. They are elongated, and some are much higher and larger than others. Some of the high rock folds in Wyoming are the giant anticlines of the Laramie, Granite, Wind River, Owl Creek, and Bighorn mountains. The Powder River, Green River, Wind River, and Bighorn basins are giant synclines. These great folds are not arranged in any definite order, as their axes trend in several directions.

The small anticlines described in this report are situated upon the sides of the giant folds or between them. They are elongated and compressed, their axes, which nearly parallel one another, trend in a northwesterly direction (see Pl. XXIII), and they are broken here and there by small faults. The axes of the small anticlines pitch either in one direction—for example, those of the anticlines that project as spurs from the giant folds—or in two directions—for example, those of the assemblage of more or less simple anticlines in the lowland area between the Laramie and Bighorn mountains.

¹ Barnett, V. H., The Douglas oil and gas field, Converse County, Wyo.: U. S. Geol. Survey Bull. 541, pp. 48-88, 1914.

² The term anticline is used here for brevity of description to include bowed-up folds that have two limbs—that is, sides in which the same strata dip in opposite directions from the axis. According to Willis (U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, p. 200, 1893), "the line or area of meeting of the sides is the axial region, the crest or crown of an anticline, the base or bottom of a syncline," and it is commonly called simply the axis. Generally the anticline is developed in nearly flat-lying rocks, and its axis pitches toward its two extremities, but in places the anticline or syncline is developed on the upturned rocks that form the rim of some large structural basin, and in that case the axis may pitch in only one direction. For convenience of description, anticlines and synclines developed on tilted beds will be called slope anticlines and slope synclines. Willis says: "When the limbs of an anticline are wide open downward further shortening of the zone of strata is possible by lessening of this angle; such may be called an open fold."

While the great, nearly level sheets of shale, sandstone (in part oil bearing), and limestone were being bent into anticlines, they were also being worn away from the crests of the anticlines, mostly by water and wind, and the detrital material so derived was in the main deposited as layers of mud and sand in the troughs of the giant synclines. These flat-lying layers filled the synclines and reached far up on the sides of the giant anticlines, nearly covering the small anticlines, some of which even now are largely hidden by the flat-lying beds. All the giant anticlines and many of the small ones have been truncated or worn down so deeply that in many places the oil-bearing sands have been exposed, allowing the oil to escape.

SWEETWATER ANTICLINE.¹

The Granite Mountains, viewed broadly, are in the middle of a great upfold, which will be referred to as the Sweetwater anticline. Although dominantly anticlinal, it is by no means a single fold but is in reality an assemblage of folds that make up one giant, deeply eroded compound anticline. The nucleus of granite in the Sweetwater Valley and Granite Mountains is surrounded by strata which dip steeply in some places and slightly in others and which now represent the outcropping, worn edges of formations that probably once extended over the anticline. The Sweetwater anticline is approximately 50 miles wide by 120 miles long, and the granite nucleus is about 25 by 100 miles. The south limb and east end of the anticline are not represented on Plate XXIII. At the west end there is an apparent continuation of the great upfold in the anticline of Sheep Mountain in Tps. 30 and 31 N., Rs. 96, 97, and 98 W. The trend of the Sweetwater anticline is almost due east, and in this respect it is like the giant anticlines of the Uinta Mountains, in the northeastern part of Utah, and the Owl Creek Mountains, in the north-central part of Wyoming, but its trend is not in harmony with the dominant northwesterly anticlines in the remainder of Wyoming.

The widely separated limbs are represented now by such folded rocks as those in the Rattlesnake Mountains and at Alkali Butte, on the north side, and those at Happy Springs and Green Mountain, on the south. Large faults occur along the south limb of the anticline, and in places, especially at Green Mountain, the formations are overturned. These folds and faults about the sides of the Sweetwater anticline and much of the granite nucleus are now covered by flat-lying strata, either light-colored or variegated, that hide for the most part the detail of the anticline.

¹ Hayden, F. V., *Exploration of the Yellowstone and Missouri rivers*, pp. 77-78, U. S. War Dept., 1890; U. S. Geol. Survey Terr. Fourth Ann. Rept., pp. 24-35, 1872. Endlich, F. M., *Report on geology of the Sweetwater district*: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 3-157, 1879.

The sedimentary formations from the Cambrian up to but not including the Wind River (see stratigraphic section on Pl. XXIII) probably once extended in great level beds across the area now occupied by the Granite Mountains and the Sweetwater Valley, as identical formations occur on both sides of the anticline, but with and after the upheaval that produced the anticline these beds were gradually eroded and for the most part if not entirely removed by streams from the crown of the anticline. The pre-Cambrian granite has been carved at least 2,000 feet deep, as the Granite Mountains rise that much above Sweetwater River, and this amount of dissection added to the total thickness of the sedimentary strata removed and the present altitude above sea level indicates an upward movement of at least 20,000 feet.

As the oil-bearing formations were removed during the upheaval of the anticline and before the deposition of the flat-lying light-colored rocks, there was and is now no opportunity for oil to migrate from them into the flat-lying rocks, as it is thought to have migrated at Douglas,¹ where oil and gas are found in flat-lying beds of the same age. Oil and gas, so far as known, have not been obtained commercially in granite. Because of these conditions the middle of the Sweetwater anticline offers no possibilities of oil and gas.

SHEEP MOUNTAIN ANTICLINE.

The Sheep Mountain anticline, which is crossed by Beaver Creek, lies in the vicinity of Hailey, a roadhouse station some 30 miles southeast of Lander. This open faulted anticline is short, lying mostly between the Big Bend of Twin Creek and Beaver Hill, a distance of 13 miles, and is almost as wide as long, but in no respect can it be called a dome. The rock strata on the northeast limb dip from 10° to 90°, with an average of about 15°, and those on the southwest limb 20° to 30°, as shown in figure 17. The outcrop of the inclined beds on the northeast side is much broader than that of the beds on the southwest, because of the lower dips and the presence of younger rocks that are not represented on the southwest side. Though the axis trends in general about N. 30° W., it is curved, with the convex side toward the southwest, as is shown by the strike of the formations involved in the fold. As the axis of the Sheep Mountain anticline passes slightly east of the axis of the Little Popo Agie anticline in T. 31 N., R. 98 W., but dies out near the Big Bend of Twin Creek, in the southeast corner of T. 32 N., R. 98 W., the anticline may be considered the generalized southward extension of the folds in the Lander oil field.² The axis is inclined and pitches northward, and

¹ Barnett, V. H., The Douglas oil and gas field, Converse County, Wyo.: U. S. Geol. Survey Bull. 541, pp. 49-88, 1914.

² Woodruff, E. G., The Lander oil field, Fremont County, Wyo.: U. S. Geol. Survey Bull. 452, pp. 22-27, 1911.

as the limbs of the anticline which open toward the granite on the Beaver divide are eroded the outcrops of none of the formations encircle it. Thrust faults at the south end of the anticline and near Sheep Mountain have disturbed the normal sequence of the rocks, as shown in figure 17. Flat-lying variegated rocks to the east and north and light-colored rocks to the east and south closely limit the visible parts of the anticline, which is separated from the folds of the Wind River Mountains by a narrow downwarp or syncline. Though the Sheep Mountain anticline is only from 9 to 18 miles southeast of the Little Popo Agie district of the Lander oil field, it probably does not contain important oil pools, because it is truncated down to the granite, all the oil-bearing formations being exposed. These conditions, in the absence of structural terraces or minor anticlines about the main upwarp to trap the oil in wet rocks, would allow any oil that was ever present in them to escape. No oil seeps were observed on the anticline.

BIG SAND DRAW ANTICLINE.

An apparently small anticline 12 miles northeast of Hailey is crossed by Big Sand Draw, a tributary of Beaver Creek, but no permanent water occurs near by. The folded rocks, which outcrop in a strip of land 6 miles long by 1 to 2 miles wide in Tps. 32 and 33 N., R. 95 W., are surrounded by flat-lying younger varicolored strata. The rock strata, as shown in figure 18, dip about 30° on each side of the axis, which trends a little west of north. The anticline as expressed by the sandstone north of Big Sand Draw is apparent, but to the south it is indistinct in the soft folded shale that is partly covered with grass. It seems from the small part of the anticline exposed that its axis pitches to the north and that none of the formations involved in the fold at present encircle the anticline.

So far as can be determined from the outcrops, the highest oil-bearing formation of Colorado age in this anticline is within reach of the drill, though at least 2,500 feet in depth. Whether or not oil pools are present in the anticline is, however, uncertain. Opportunity occurred before the deposition of the flat-lying beds for the oil, if then present, to migrate to the surface and escape. Likewise, since the deposition of the flat-lying

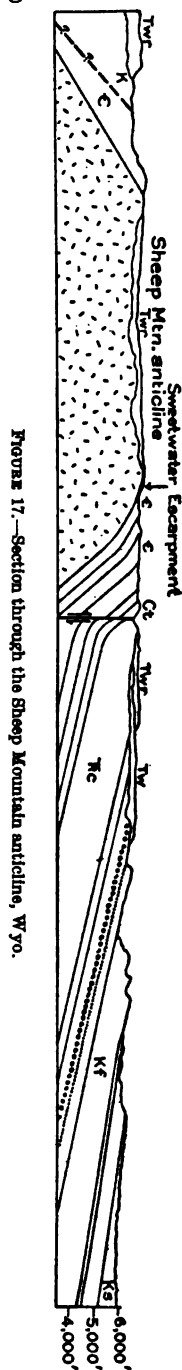


FIGURE 17.—Section through the Sheep Mountain anticline, Wyo.



FIGURE 18.—Section through the Big Sand Draw, Alkali Butte, and Conant Creek anticlines, Wyo.

beds oil may have migrated upward and accumulated in inclined beds abutting against the overlying horizontal beds or in the base of the horizontal beds. This could have taken place only in the area south of the exposed part of the anticline. If it is assumed that the axis pitches in both directions and that the dark adobe shale exposed south of Big Sand Draw occupies the middle of the anticline, thereby tightly closing over the oil-bearing sandstone below, this anticline would be perhaps the most promising in the entire field, as oil pools might be present in the sandstone thus protected.

ALKALI BUTTE ANTICLINE.

A northward-pitching, closely folded anticline north of the Sweetwater escarpment in the vicinity of Alkali Butte and Mount Rogers forms a part of the complex folds of the so-called Riverton oil field and is reached with least difficulty by a trip of about 15 miles southeast from Riverton, a station on the Chicago & Northwestern Railway. The area about Mount Rogers was described by Aughey¹ as the Beaver oil basin. The oil, according to him, is of high grade, of 0.968 specific gravity, and of a mahogany color. Mount Rogers is sometimes spoken of as being on Oil Mountain Ridge, but that name leads to confusion with Oil Mountain, in the eastern part of the field, so the name Mount Rogers is preferable.

That part of the northwestward-trending anticline which can be seen is narrow and about 15 miles long. Its visible part south of Mount Rogers is shown by the closely folded shale and sandstone that pass beneath the flat-lying light-colored strata forming the Sweet-water escarpment. These sandstones, tilted at angles from 30° to 90°, form sharp ridges about 2 miles long in a lowland of shale. (See fig. 18.) The sandstones dip rather abruptly in the northwest corner of T. 33 N., R. 94 W., at an oil seep, and to the north the arch is low but is continued in shale to the vicinity of Alkali Butte, where less closely folded overlying sandstones form the north end of the anticline. The folded strata disappear beneath the nearly level varicolored beds 3 miles north of the butte, some distance north of the position shown by Woodruff and Winchester.³ In passing

¹ Aughey, Samuel, Wyoming Territorial Geologist Ann. Rept., 1886, pp. 124-129.

² Woodruff, E. G., and Winchester, D. E., Coal fields of the Wind River region, Fremont and Natrona counties, Wyo.: U. S. Geol. Survey Bull. 471, pls. 49, 53, 1912.

along the crest or crown of the anticline it will be seen that the fold is sinuous but that both ends trend almost due north. The bend in the middle offsets the two straight ends about 2 miles, though there is no large fault. The axis rises to the south, as is shown by the absence of any visible southward-dipping strata. Erosion has left the anticline incomplete in the sense that it is not encircled by the formations involved in the fold. The anticline was developed on the north slope of the giant Sweetwater anticline and so is called a slope anticline.

In the northwest corner of T. 33 N., R. 94 W. (undivided township), small oil seeps occur in Frontier sands north of Mount Rogers and just south of the place where they dip below the shale. From one of the seeps a little west of the axis a film of oil accumulates on a pool of stagnant water. On the axis oil escapes from the next lower sandstone and remains in little depressions or on warm days trickles down the slope of the sandstone. Some black residue indicates the drying of the oil as it escapes. The largest seeps are about half a mile to the south of the seeps above described and north of Mount Rogers, a high, flat-topped hill, on the axis of the anticline, where oil oozes from a still lower sandstone (Peay) and accumulates in cow tracks and other small depressions. Pieces of old rusty machinery lying about are signs of a former intention to prospect, possibly that of the Omaha Oil & Transportation Co., mentioned by Aughey. The record of the well in the position of the unsurveyed SW. $\frac{1}{4}$ sec. 29, T. 33 N., R. 94 W., on Conant Creek, was not obtained, but seemingly it was a dry hole.

A temporarily abandoned well of the Western States Oil Co., begun in the summer of 1913, is 2 miles southeast of the oil seeps, in the syncline between the Alkali Butte and the Conant Creek anticlines. It is reported that at a depth of 1,300 feet a showing of oil was found in sandstone which is certainly the same as that at the oil seeps in the sharp ridge at Mount Rogers.

The Ohio well, drilled in the fall of 1913 a short distance west of the axis of the anticline, in the NE. $\frac{1}{4}$ sec. 2, T. 33 N., R. 94 W., was a dry hole, drilled in dark shale to a depth of 2,930 feet. At a depth of 177 feet, in a thin, soft sandstone, a little gas and oil were struck. No sand was encountered below 1,070 feet, and no water at any depth.

The Alkali Butte anticline is not regarded as a favorable structure for the accumulation of oil and gas, because the upper oil-bearing sandstones have been eroded from its crown and because the axis rises to the south, so that there is no domed area in which the lower oil-bearing sandstones and conglomerates are closed tightly below shale. In such an anticline, where the sandstones are saturated with

water, any oil or gas once contained in them has presumably had an opportunity to escape. The oil seeps described above indicate that this process is still in operation. There is, however, a chance that an oil pool may be found even in spite of these unfavorable conditions.

CONANT CREEK ANTICLINE.

Southwest of Delfelder's ranch, on the heads of Long and Conant creeks, is an open complex anticline crossed by the Sweetwater escarpment. Small springs of good water are present along its east side and south end, and large sulphur springs issue in the southeast corner of T. 33 N., R. 94 W., from beds near its axis. The visible part of the anticline covers less than two townships and is limited on the north and east by flat-lying variegated beds and on the south by nearly level light-colored strata. In plan the Conant Creek anticline is short, owing in part to overlapping horizontal beds but more to the character of the fold; its axis is sinuous and pitches only in one direction. It has, as shown in figure 18 (p. 252), a wide northeast limb and a narrow west limb. Its complexity is due to three minor folds on the main anticline and to faults. One of the minor folds, which has dips of 18° to 29° and pitches away from the main anticline, is on the east side in the northwest corner of T. 32 N., R. 93 W.; another occurs at Sulphur Springs, and still another to the south, which is crossed near the middle by the Sweetwater escarpment. The last two, whose axes are slightly offset, are separated by a branch of Conant Creek and really make a large part of the main anticline. The dips on the east flank of the south fold range from 12° to 85° and those on the west flank from 8° to 20° . Small faults occur at the north end of the south fold, and a large strike fault on the west limb of the northernmost fold possibly furnishes opportunity for the escape of the water at Sulphur Springs. The offsetting of the formations in the north-central part of T. 32 N., R. 93 W. is more probably due to a fault than to an acute fold, though this is not evident from the manner of grouping formations on the map (Pl. XXIII).

In the general syncline between the Conant Creek and Alkali Butte anticlines there is a small, slightly arched anticline that pitches northward like those on each side. This fold, the Big Sand Draw and Alkali Butte anticlines, and the minor folds of the Conant Creek anticline resemble in shape and position the fingers of a hand.

A cross section through the anticline near Sulphur Springs (see fig. 18) displays dips of 32° to 65° on the narrow west limb, which is less than a mile wide, and dips of 30° to 47° in the same strata on the northeast limb. The outcrop of these beds on the west limb is about $2\frac{1}{2}$ miles wide, but that on the east limb is about 8 miles wide, the

greater width being due in part to low dips, but more to the presence of a great thickness of beds that are not found on the west limb or in the syncline between the Alkali Butte and Conant Creek anticlines. Viewed lengthwise the anticline shows a great thickness of beds dipping northward but no corresponding beds dipping southward. The absence of southward dips indicates the deep erosion which the anticline has suffered, also that it is a slope anticline. The anticline seems to end about 3 miles north of Sulphur Springs, as the massive sandstones along the north side of T. 33 N., R. 94 W., are not noticeably affected by the fold.

The Conant Creek anticline is not a favorable fold for the accumulation of oil and gas, because all the oil-bearing formations are stripped from its crest and even though minor folds are present they involve mostly the older formations, which generally are not oil bearing. Thus in no part of the anticline are the Cretaceous oil-bearing sandstones tightly sealed beneath shale in such a manner as to lead to the retention of oil and gas in the presence of water.

BUCK SPRINGS ANTICLINE.

An anticline is indicated by a small area of tilted sandstone beds surrounded by flat-lying variegated strata at Buck Springs, in T. 34 N., Rs. 92 and 93 W., 4 miles east of Delfelder's ranch. In plan the



FIGURE 19.—Section through the Buck Springs anticline, Wyo.

visible part of the anticline is arrow-shaped, pointing northwest, and the corresponding beds on both sides dip away from the axis about 12° or less, as indicated in figure 19. Viewed lengthwise the anticline shows only northwestward-dipping beds, and this fact, considered with near-by exposures of the same beds that are involved in the arch, indicates an inclined axis or a slope anticline.

The relation of the Buck Springs anticline to other anticlines in its vicinity is purely speculative, because of the surrounding flat-lying beds. However, it is reasonably certain that there is a fault trending northeast from a point near the sharp bend of Long Creek possibly to the southwest corner of T. 34 N., R. 92 W. No definite fault plane is visible, its presence being inferred by the offset in position of the outcrop of some of the older formations in the Conant Creek anticline. The map, on which the many formations involved in the folds are combined into only three groups, does not adequately indicate the amount of the offset.

The Buck Springs anticline is not attractive as oil territory, because the oil-bearing Frontier formation is beyond easy reach of the drill, lying at a depth of more than 4,000 feet, and because of the pitch of the axis as outlined above.

DUTTON ANTICLINE.

An open northward-pitching slope anticline is situated in what is known as Dutton Basin, north of the Sweetwater escarpment, 6 miles west of the north end of the Rattlesnake Mountains and from 12 to 25 miles south of Moneta, a station on the Chicago & Northwestern Railway. This locality has been referred to in short notes by Aughey¹ and Ricketts² as the Dutton oil basin, and later described by Knight³ and by Woodruff and Winchester⁴ as the termination of an anticlinal fold. The part of the anticline not covered by flat-lying variegated beds is short and about one-third as wide as long. The southern part is marked by northward-converging sandstone ridges, so that in plan the formations or contour lines drawn on a particular bed resemble a series of nesting V's opening to the southeast. None of the beds involved in the fold at present entirely encircle the anticline, and viewed from the side it shows a series of northwestward-dipping beds and an inclined axis.

The west limb is narrow, with the beds dipping 20° to 45°; on the broad east limb the same beds dip 12° to 33°. (See fig. 20.) The



FIGURE 20.—Section through the Dutton anticline, Wyo.

higher and younger beds involved in the fold on the east limb are not repeated on the west limb, being absent because of the oblique angle which the axis makes with that of the giant Sweetwater anticline and because they have been eroded away. Erosion has stripped all the possible oil-bearing formations from the crest or crown of the anticline, and it is probable that truncation cut down even to the granite prior to the deposition of the flat-lying beds.

The formations on the west limb of the anticline probably join with the same formations exposed near the head of Muskrat Creek and farther west with those on Conant Creek, as indicated on the map (Pl. XXIII) by the dashed line under the stippled pattern. The northward-dipping beds in Tps. 32 and 33 N., R. 91 W., on Muskrat

¹ Aughey, Samuel, Wyoming Territorial Geologist Ann. Rept., 1886, p. 120.

² Ricketts, L. D., Wyoming Territorial Geologist Ann. Rept., 1888, p. 35.

³ Knight, W. C., Wyoming Univ. School of Mines, Petroleum ser., Bull. 4, pp. 14-19, 1901.

⁴ Woodruff, E. G., and Winchester, D. E., Coal fields of the Wind River region, Fremont and Natrona Counties, Wyo.: U. S. Geol. Survey Bull. 471, p. 551, pl. 49, 1912.

Creek, are a part of the north limb of the giant Sweetwater anticline. Likewise, those on the east limb of the Dutton anticline probably join the same formations at the north end of the Rattlesnake Mountains. The Dutton anticline is separated from the Rattlesnake anticline by a shallow syncline occupied by Deer Creek and extending south past Black Mountain to the head of Dry Creek. (See fig. 21.)

The Dutton anticline is commonly spoken of as the Dutton Basin oil field, but like the "Riverton oil field" it does not deserve the name. Oil seeps are rare and there are (June, 1916) no producing oil wells. The small outcrop of Tensleep sandstone in sec. 13, T. 33 N., R. 90 W., is saturated with oil, but the seeps mentioned by Knight¹ as occurring in the Dakota sandstone, "Niobrara sandstone" [probably Frontier], and Tertiary beds were not found. Near the apex of the converging sandstone ridges there are some bog holes from which a small quantity of bad water issues, but no oil was seen. About small vents in these places an occasional gas bubble escapes, and there is a distinct odor of hydrogen sulphide. The field has been prospected recently by numerous assessment wells and in the early days by pits. A well drilled on the axis, about a mile north of the apex of the united hogback ridges of the two flanks of the fold, obtained a showing of oil and gas. The casing was still in the hole at the time of the writer's examination, and water stood only a few feet below its top. A small amount of gas was being given off, and a sample of heavy dark-brown oil was obtained from the top of the water. The oil probably came from the Wall Creek sand, as the well is reported to have been drilled to a depth of about 1,060 feet. It was not analyzed.

Because any oil or gas which may have been contained in the formations has had ample chance to escape from their truncated edges during the erosion periods preceding and following the deposition of the flat-lying beds, and also because of the meager showing of oil seeps, it seems improbable that any considerable amount of oil has been conserved in this much eroded anticline. Small quantities may be entrapped where the oil-bearing formations abut

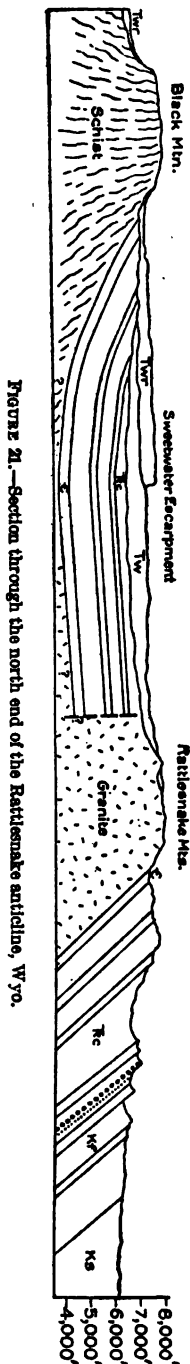


FIGURE 21.—Section through the north end of the Rattlesnake anticline, Wyo.

¹ Knight, W. C., op. cit., pp. 14-18.

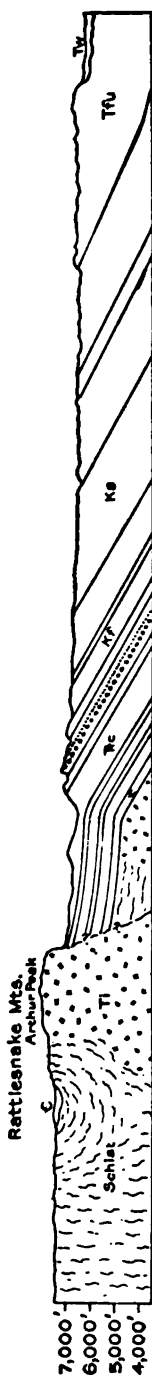


FIGURE 22.—Section through the Rattlesnake anticline at Arthur Peak, Wyo.

against the flat-lying beds, but even this possibility seems remote.

RATTLESNAKE ANTICLINE (?).

The fold of the isolated Rattlesnake Mountains is about 50 miles west of Casper and 15 miles southwest of Waltman. The northwest end is anticlinal and faulted, as shown in figure 21, whereas from Wallace Creek southeast to Horse Creek the strata dip for the most part in one direction (northeast) and are disturbed by large intrusive masses, as shown in figure 22. The range has a length of about 25 miles, trends about N. 45° W., and parallels most of the anticlines in the area. Viewed broadly, it is a deeply eroded anticline resting on the granitic rocks of the Sweetwater Valley and formed on the northern limb of the giant Sweetwater anticline. Knight¹ considered the range as due to a great overthrust fault and shows the fold as a large monocline—that is, a fold in which the strata all dip one way—and Trumbull,² apparently following Knight, also considered it a monocline, but a map by Darton³ shows a vestige of a southwest limb at the north end. Along the northeast side of the mountains are the Big-horn, Rattlesnake, and Arago oil basins of some writers.

In plan the visible part of the fold is about one-third as wide as long and is encroached upon on all sides by the overlapping horizontal white and variegated beds deposited during and after the principal period of deformation. These level beds conceal the true relation of the Alcova and Dutton anticlines to the folds in the Rattlesnake Mountains. The outcrops of the formations involved in the folds of the Rattlesnake Mountains occur, in plan, in parallel bands with a southwestward-bending hook at the north end. At both ends they pass under younger flat beds. The normal dip and strike of the strata have been disturbed by late intrusive rocks, as shown in figure 22.

¹ Knight, W. C., op. cit., p. 21.

² Trumbull, L. W., Prospective oil fields: Wyoming Geol. Survey Bull. 3, pp. 9-10, 1913; Light-oil fields of Wyoming: Wyoming Geol. Survey Bull. 12, p. 125, 1916.

³ Darton, N. H., Paleozoic and Mesozoic of central Wyoming: Geol. Soc. America Bull., vol. 19, pl. 22, 1908.

This probably explains a small shallow syncline between Arthur Peak and Devils Saddle, in T. 32 N., Rs. 86 and 87 W. Large masses of intrusive porphyritic andesite form Garfield Peak, Arthur Peak, Devils Saddle, and Goat Mountain. The large white mineral in the porphyry is oligoclase-albite and the large black ones alkali pyroxenes. Smaller masses of the same rock are found also at many other places, shown on Plate XXIII. The sedimentary rocks surrounding these igneous rocks usually dip away from the intruded mass, but not uncommonly they are overturned and dip toward it.

A transverse section through the range south of the J E ranch and from Black Mountain to Wallace Creek (fig. 21) shows only a few beds dipping at low angles into the Deer Creek syncline, but east of the granite core these beds, as well as those which are shown by cross hatching on the map, dip about 45° E., and many others, mostly those not indicated by a pattern on the map, dip east at angles of 25° or more for a distance of over 6 miles. North of this section the beds on the west limb of the fold dip 37° or more, and in secs. 14, 24, and 25, T. 34 N., R. 89 W., a minor short syncline is developed on the main fold, as is shown on the map by the indentation of the cross-hatched area. A similar section through Arthur Peak (fig. 22) shows only eastward-dipping strata, tilted at angles of 16° to 40° , which gradually flatten and pass under the nearly level variegated beds and into the F L syncline on the east. The higher dips in general occur along the hogbacks forming the foothills of the mountains (the outer part of the area indicated by cross-hatching on the map).

The range viewed lengthwise along the summit displays from the southeast for 15 miles a granite and schist base, partly veneered with flat strata, which are here and there distorted by late intrusions. The folded sedimentary formations at the northwest end of the mountains dip on an average about 24° N. for a distance of 8 miles and then pass beneath the horizontal variegated beds.

It is possible that near the head of Horse Creek there is along the southwest side of the mountains a northwestward-trending fault. A large fault here, which was assumed by Knight¹ to connect with the alleged large fault at Alcova, is highly problematic, but credence is lent to this assumption by the fact that a large warm spring in sec. 35, T. 32 N., R. 86 W., issues from the supposed fault plane. Probably there is no fault of great magnitude at this place, for there is no marked offset of the formations near Deer Creek, in T. 34 N., R. 89 W., and the south end of the supposed fault near Alcova is not evident. There is, however, in T. 33 N., R. 88 W., at the north end of the Rattlesnake Mountains, a fault a few miles in length, but no further positive evidence was seen of such a large fault as would be necessary to account

¹ Knight, W. C., *op. cit.*, p. 21.

for the absence in the Sweetwater Valley, southwest of the Rattlesnake Mountains, of the older as well as the younger folded formations that are present on the northeast side of the mountains. The formations probably once extended across Sweetwater Valley and have been eroded, because all of them having similar characteristics are found at Whiskey Peak and Green Mountain in Tps. 27 and 28 N., Rs. 89 and 90 W.

The indications of oil found at many places in the Rattlesnake Mountains are confined chiefly to the conglomerate (see section on Pl. XXIII) in the lower part of the Cretaceous and to the Dakota. These have been described by Aughey, Ricketts, Knight, and Trumbull in the papers already cited. At the Lew Smith spring, in sec. 26, T. 32 N., R. 86 W., a very small quantity of dark asphaltum issues from the bottom of a ravine in the flat-lying beds. It originates in either the conglomerate or the sandstone (Dakota), which are only a few feet below the surface. Southwest of Oil City, where the same conglomerate is more extensively saturated, a dark asphaltum oozes from its outcrop. A small outcrop of a higher sandstone (Frontier) in this vicinity, in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 8, T. 32 N., R. 86 W., shows traces of oil. Between this locality and Garfield Peak no oil was found, but north of the peak, on Wallace Creek and on small draws cutting the upturned rocks in the hogback ridges from sec. 28, T. 33 N., R. 87 W., to sec. 34, T. 34 N., R. 88 W., the same conglomerate and sandstones as are found farther south are saturated with oil, and from seeps along the creek valleys dark asphaltum accumulates to considerable depth over many square rods. In this district there are traces of oil in all the formations from the Chugwater to the Dakota, also in the Frontier, and even the Teapot sandstone at Phayles Reef, in secs. 4, 5, and 9, T. 33 N., R. 87 W., is saturated with oil. The indications of oil are less and less pronounced toward the north end of the mountains, where there are no showings whatever.

The exact location of the two wells of the Central Association of Wyoming, drilled 700 and 900 feet deep, which passed through the "Fox Hills" [Frontier] and obtained some light oil, and of the one sunk by the Northwestern Oil Co. in September, 1887, which also obtained some light oil and water at 480 feet in the "Fox Hills" [Frontier], is not recorded¹ unless, as seems probable, they are the ones shown by Knight in sec. 34 and in sec. 28 or 29, T. 34 N., R. 88 W.

Two other shallow wells have been drilled along the mountains, one 1,130 feet deep at Oil City, which struck only a slight showing of oil at a depth of 500 feet, and one near the west quarter corner of sec. 20, T. 33 N., R. 87 W., which obtained a showing of oil and gas.

¹ Aughey, Samuel, op. cit., p. 134. Ricketts, L. W., op. cit., p. 35. Knight, W. C., op. cit., p. 28, map.

During the summer of 1913 some prospecting was done with Star rigs along the east side of the mountains, but no oil was obtained.

The Rattlesnake anticline is not considered favorable for the conservation of oil and gas, because none of the oil-bearing formations are closed tightly below thick shale beds in anticlinal folds. The fact that oil escapes from the outcrops of the formations along the east flank of the mountains seems to signify that most of the oil has been forced by water pressure to the outcropping edges of the formations, so that little remains in them at present, and wells drilled down the dip from the outcrop may be expected to strike plenty of water. It is not considered that the outcrops of these more or less saturated sandstones and conglomerate are so clogged with oxidized oil and asphalt as to make them reservoirs for oil down the dip, as occurs in some of the California fields.¹ This unfavorable view of the significance of such seeps is supported by the fact that the beds dip rather uniformly along the whole front of the mountains except in the area affected by the Wallace Creek dome (?), so that no structural terraces or minor anticlines occur.

WALLACE CREEK DOME (?).

A fold somewhat resembling a dome occurs in T. 34 N., R. 87 W., far out on the northeastward-sloping beds involved in the upturned limb of the Rattlesnake anticline or along the west limb of the F L syncline, according to the viewpoint of the individual. The syncline has been referred to as the Powder River syncline.² Wallace Creek, a tributary of Powder River, has eroded the flat-lying variegated beds from most of the township and displayed older folded rocks, which show dips of 3° to 10° or in some places 17°. In a section taken in a N. 45° E. direction across the northwestern part of the township there are strata dipping southwest as well as northeast, but in one taken in a similar direction through the dome and along the creek only eastward-dipping beds occur. A low arch is present in a section taken in a northwesterly direction. The folding seemingly did not progress sufficiently to form a complete dome, as there are no southwest dips along the south side of T. 34 N., R. 87 W.

The Wallace Creek dome (?) is less attractive than some other areas as a possible oil reservoir, because the proved oil-bearing formations are too deep to be reached easily by the drill. The highest sandstone showing oil in the region is the one saturated with oil at Phayles Reef, in secs. 4, 5, and 9, T. 33 N., R. 87 W. It is at least 4,000

¹ Arnold, Ralph, and Anderson, Robert, *Geology and oil resources of the Coalinga district, Cal.*: U. S. Geol. Survey Bull. 398, pp. 187-189, 1910.

² Woodruff, E. G., and Winchester, D. E., *Coal fields of the Wind River region, Fremont and Natrona counties, Wyo.*: U. S. Geol. Survey Bull. 471, p. 553, pls. 49, 56, 1912.

feet and perhaps much more below the surface. Before the Wallace Creek dome (?) is finally condemned as oil territory, a well should be drilled deep enough to test this sandstone. If a test well is to be drilled, preparations should be made to go 6,000 feet or more if necessary.¹

The Franco-American well, in sec. 16, T. 34 N., R. 87 W., though not completed when the area was examined, struck no oil. The well was sunk more than 2,000 feet and may have reached well into the Lance formation.

It is interesting to note that the largest showings of oil in the upturned beds along the Rattlesnake Mountains are almost directly opposite the dome on Wallace Creek and that the heavily saturated Phayles Reef lies in the intervening area, but it is impossible to say whether or not this intervening area contains a body of oil.

ALCOVA ANTICLINE.

The town of Alcova is about 30 miles up North Platte River from Casper, in the midst of an area of folded rocks that have been exposed by the erosion of the river. The fold at Alcova may be considered as the southward-pitching end of an anticline that is paralleled on the east by the F L syncline and on the west by a narrow syncline and farther west by a monocline resting on the granitic nucleus of the giant Sweetwater anticline. The Alcova anticline is believed to be a part of the limb of the large Sweetwater fold.

The geology at Alcova has been briefly described by Knight,² who shows the tilted beds as a faulted monocline.¹ In a later paper³ he refers to the fault as the Fremont thrust fault. The stratigraphy of this locality has been described briefly by Darton,⁴ who shows the folds as a faulted anticline and monocline.

The visible part of the unsymmetrical anticline is about 16 miles long by about 7 miles wide, and it trends about N. 60° W. In passing along the southeastward-pitching axis from the northwest corner of T. 30 N., R. 83 W., through the Hot Springs gorge to the vicinity of the southeast corner of T. 30 N., R. 82 W., successively higher or younger rocks are encountered. The strata on the broad northeast limb dip on an average 10°, whereas those on the narrow southwest limb dip as much as 60°, as shown in figure 23.

The formations involved in the fold at first sight seem to be repeated by faulting, because the broad band of red rocks (Chugwater formation) on which Alcova is located is apparently repeated farther

¹ Trumbull, L. W., Prospective oil field at Upton, Buck Creek, Rattlesnake Mountains, and Labarge: Wyoming Geol. Survey Bull. 5, p. 10, 1913.

² Knight, W. C., Artesian basins of Wyoming: Wyoming Univ. Bull. 45, p. 236, 1900.

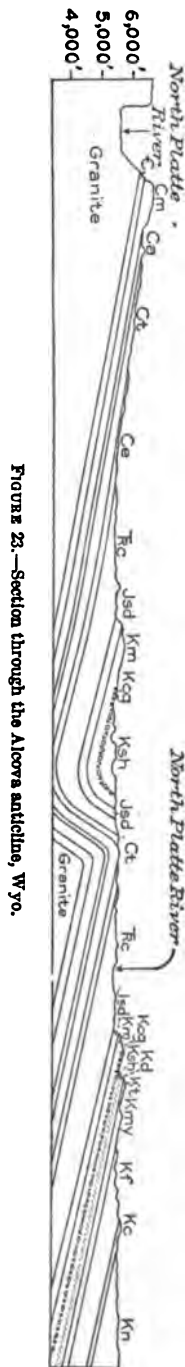
³ Knight, W. C., Wyoming Univ. School of Mines, Petroleum ser., Bull. 4, p. 21, 1901.

⁴ Darton, N. H., Paleozoic and Mesozoic of central Wyoming: Geol. Soc. America Bull., vol. 19, pp. 406-488, pl. 21, 1908.

up the North Platte by the alleged Fremont thrust fault, as shown by Knight and Darton, but on closer inspection it is found that the formations from the Chugwater up to the Niobrara may be traced continuously from the east limb of the anticline around the point of the fold and along the west limb, except where they are covered by flat-lying beds, as just west of the river, and connected with the same formations in the monocline below the Pathfinder dam. The traces of these formation boundaries are of the form of very much depressed Z's. The formations have been somewhat compressed on the west limb of the Alcova anticline, for even though the beds are on edge west of Hot Springs and along the Devils Gardens, there is scarcely sufficient width of outcrop to accommodate the normal thickness of the formations. It is possible that there are some small strike faults along the crushed zone that represent the southeastward dying out of the large fault on the southwest side of the Rattlesnake Mountains assumed by Knight. A small normal fault trending southwest about 4 miles northwest of Alcova and 3 miles east of the Childress ranch, offsets the formations about 200 feet.

The exact relation of the folds at Alcova to those in the Rattlesnake Mountains, on the northwest, or those in the Freezeout Hills, on the south, is obscured by the unconformable flat-lying beds. The strike of the beds in the Rattlesnake Mountains is in harmony with the strike of the beds at Alcova, and as the formations are the same in each area, they probably join beneath the flat-lying beds. The broken line beneath the stippled pattern on the map indicates such a connection. The intervening distance is about 12 miles, and it is assumed that truncated edges of the formations from Cambrian to Fort Union abut against the flat-lying beds. It is possible that where the formations that show large seeps of oil along the front of the Rattlesnake Mountains abut against the level beds these overlying beds may act as a trap, and oil pools may have formed either in the sands below or in the level beds themselves, but it is believed that no large pools may be expected here.

The area immediately about Alcova apparently has no future as oil territory, because the anticline is eroded below



all the oil-bearing formations, allowing easy escape of oil and gas from the outcrop and leaving no favorable places for pools to be formed. No oil seeps were seen about Alcova, and the well drilled several years ago in sec. 25, T. 30 N., R. 83 W., 2 miles above the village, was a dry hole. Its location is in the syncline between the Alcova anticline and the monocline to the west and is in as unfavorable a site for a test well as could have been selected.

BATES HOLE ANTICLINE.

The anticline in Tps. 30 and 31 N., R. 81 W., in the middle of the Bates Hole country, is a small upwarp trending approximately N. 45° W. It lies a short distance northeast of the folded rocks at Alcova, south of the Goose Egg anticline, and immediately west of the highly folded and faulted rocks of the Laramie Mountains. It is in line with the axis of the F L syncline, which lies west of the Pine dome and Oil Mountain anticline. The axis of the Bates Hole anticline pitches at both ends at low angles and has a sag a short distance north of the south township line of T. 31 N., R. 81 W., making two unequal parts, of which the larger is the broad southern portion of the anticline, in the northeast corner of T. 30 N., R. 81 W., and the smaller the narrow northern portion of the anticline, in the southwest corner of T. 31 N., R. 81 W. A small strike fault, not shown on Plate XXIII, occurs south of the middle of the anticline. The anticline has a narrow west limb in which the beds dip from 70° to 90° and a broad east limb in which the same beds dip less than 40°.

West of the small north end of the Bates Hole anticline and separated from it by a narrow syncline is a small dome or short simple anticline covering less than a square mile. The dips in the encircling sandstone ridges that indicate its presence are about 50° on all sides.

In this small dome and also in the north end of the main anticline the Dakota sandstone is from 500 to 800 feet below the surface. The Tensleep sandstone is less than 1,500 feet below the surface in the middle of the southern part of the anticline. Because of the presence of this and other sands which yield oil or show indications of it in other localities, there is a possibility that the Bates Hole anticline may contain oil or gas. No indications of oil, however, were found on it at the surface.

GOOSE EGG ANTICLINE.

The faulted anticlinal fold of the Casper Range, a part of the giant fold of the Laramie Mountains, enters the southeast corner of this field in T. 32 N., R. 81 W., and structurally terminates in the anticline forming Goose Egg Mountain, a small outlier separated from

the main range by North Platte River.¹ The mountain rises about 1,000 feet above the river.

The Goose Egg anticline as expressed in plan consists of a series of nesting V-shaped lines representing structure contours or even contacts of formations that open toward the Laramie Mountains and point westward. Its axis, sloping down from the giant anticline of the Laramie Mountains, pitches at a fairly high angle and trends a little south of west, at a considerable angle to the axes of the surrounding anticlines. (See Pl. XXIII.) The Casper fault,² which brings the granite to the surface in the Laramie Mountains, and the Emigrant Gap anticline limit the Goose Egg anticline on the northeast. As viewed in a north-south cross section near the highest part of the mountain the strata on the south flank of the anticline dip from 16° or possibly less to 21°, as shown in figure 24, but north of the axis in a narrow crushed zone they dip at very much higher angles and are even overturned. North of the highly tilted beds the dips decrease rapidly and the strata flatten, forming the large

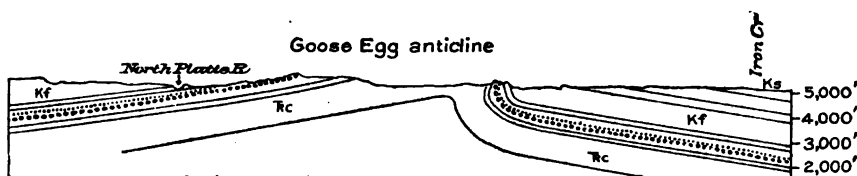


FIGURE 24.—Section through the Goose Egg anticline, Wyo.

bulge or arc on the north side of the anticline, as indicated in Plate XXIII.

The Goose Egg anticline is not considered favorable for the accumulation of oil and gas, because all the oil-bearing formations are exposed at the surface except the Tensleep sandstone, which is only a few feet below the river. This probably is water-logged even on the crown of the anticline, for a large spring that is used to irrigate about 1,000 acres of Bessemer Flats issues from the base of the Chugwater formation in the crest of the anticline.

IRON CREEK ANTICLINE.

The Iron Creek anticline occupies a small area in the northwest corner of T. 32 N., R. 82 W., where its crest is shown by inclined sandstone beds that form encircling ridges about an inner shale basin, and each sandstone is in turn surrounded by a shale valley.³

¹ Hayden, F. V., U. S. Geol. Survey Terr. Fourth Ann. Rept., pp. 26-28, 1872.

² Hayden, F. V., *idem*. Darton, N. H., Paleozoic and Mesozoic of central Wyoming: Geol. Soc. America Bull., vol. 19, pl. 21, 1908; Preliminary report on the geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, pp. 53-55, 1905. Barnett, V. H., Possibilities of oil in the Big Muddy dome, Converse and Natrona counties, Wyo.: U. S. Geol. Survey Bull. 581, pp. 105-117, 1915. Spencer, A. C., The Atlantic gold district and North Laramie Mountains, Wyo.: U. S. Geol. Survey Bull. 626, pl. 4, 1916.

³ Hayden, F. V., *op. cit.*, p. 28.

It is the fold connecting the Oil Mountain and Goose Egg anticlines. Like the Oil Mountain anticline, it trends northwest, but it is nearly at right angles with the Goose Egg anticline. The strata on the north end of the Iron Creek anticline dip 42° ; those on the south end only 11° . The strata on the east side dip from 20° to 60° and the same beds on the west side from 31° to 62° , as shown in figure 25.



FIGURE 25.—Section through the Iron Creek anticline, Wyo.

The fold is ideal for the accumulation of oil and gas in wet rocks, but only the drill will show whether or not oil, gas, or water occurs in the Cretaceous sands below the Frontier sandstones, or in the conglomerate, sealed below impervious shale.

OIL MOUNTAIN ANTICLINE.

The Oil Mountain anticline, in Tps. 32 and 33 N., R. 82 W., a little over 15 miles west of Casper, is a small unsymmetrical fold, whose middle portion is indicated by concentric shale valleys and sandstone and conglomerate ridges that rise considerably above the surrounding country. The lower and outer portions of the flanks of the anticline, formed of soft shale, are less conspicuous than the inner portion, where the sandstones are exposed. The strata of the west limb dip rather uniformly at angles of 29° to 46° close to the mountain, but farther west the dips are as great as 80° ; those on the east limb dip only 7° out on the flanks, but are vertical or even overturned close to the axis. The axis pitches abruptly southward and gently northward. (See fig. 26.) A strike fault with a throw of over 1,000 feet repeats the outcrop of some of the formations northwest of Oil Mountain, and the oil spring in sec. 28, T. 33 N., R. 82 W., is on the fault plane. East of the fault the rocks dip at low angles (3° to 9°) and show a marked flattening of the anticline in secs. 15, 16, 17, 19, 20, and 21, T. 33 N., R. 82 W., as indicated in figure 27. This flattening lies mostly south of Poison Spider Creek and presumably is the "peculiar U-shaped fault" of Knight.¹

At the oil spring in sec. 28 heavy dark oil accumulates on water in an old prospect pit. The ground about the spring is slightly saturated and pieces of asphaltum lie on the surface. The oil possibly comes from the Lower Cretaceous conglomerate, which is only a few feet below the surface on the west side of the fault plane.

The Tensleep sandstone lies about 1,500 feet below the surface on the crest of the Oil Mountain anticline, and the Lower Cretaceous

¹ Knight, W. C., Wyoming Univ. School of Mines, Petroleum ser., Bull. 4, pp. 33-35, 1901.



FIGURE 26.—Section along the axis of the Oil Mountain anticline, the minor anticlines between Poison Spider and Casper creeks, and the Pine dome, Wyo.

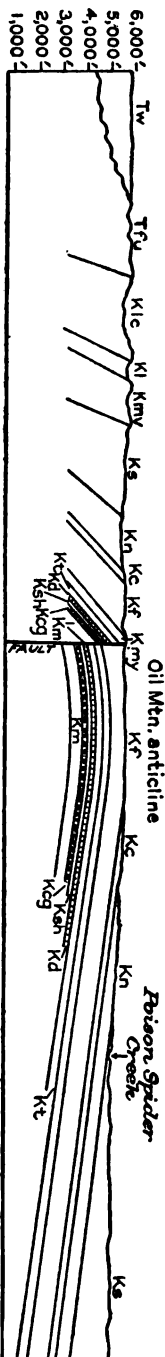


FIGURE 27.—Section through the Oil Mountain anticline, Wyo.

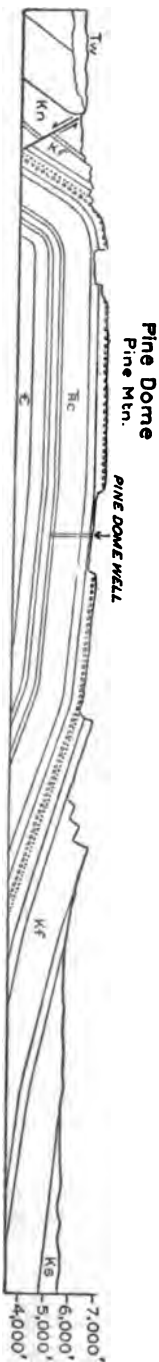


FIGURE 28.—Section through the Pine dome, Wyo.

conglomerate is only a short distance below the surface just west of the fault plane in sec. 28. These two localities, which are the most favorable for the retention of oil because of their position in the anticline and because some of the oil-bearing sands are sealed in the beds underlying them, should be tested before the Oil Mountain anticline is condemned as nonoil land.

MINOR ANTICLINES BETWEEN POISON SPIDER CREEK AND THE SOUTH FORK OF CASPER CREEK.

Between Poison Spider Creek and the south fork of Casper Creek there are three minor anticlines on the general anticline which extends from the Pine dome to Oil Mountain. These folds when compared with the Pine dome and the Oil Mountain anticline are small in area as well as in degree of deformation and topographic effect. They are separated from one another by transverse sags developed on the main anticline, as shown in figure 26. The northernmost of the three minor anticlines is about 4 miles long, and the same strata on both sides of it dip about equally at angles ranging from 15° to 30° . The middle one is about 3 miles long; the strata on the west side dip from 7° to 60° , but those on the east side only from 3° to 24° . The southernmost of the three is very small, being less than a mile long. The strata on the east side dip from 6° to 49° and those on the west 10° . The dip of 49° on the east side is exceptionally steep.

These minor anticlines doubtless have afforded opportunities for the accumulation of oil and gas, but whether they still contain oil and gas can not be determined with certainty prior to actual drilling. The two wells already drilled are near the axis of the general fold extending from the Pine dome to the Oil Mountain anticline, but in the cross sag between the Oil Mountain anticline and the minor anticlines. One of these, the Guthery well, 960 feet deep, in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 18, T. 33 N., R. 82 W., is reported to have obtained a showing of oil. The Ohio well, in the NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 18, T. 33 N., R. 82 W., obtained showings of oil in the Dakota sandstone, the Lower Cretaceous conglomerate, and the Morrison formation, but found the Tensleep sandstone, at a depth of 2,715 feet, water-logged. These sands, which are all sealed below impervious shales in the crowns of the anticlines, should be properly tested by the drill before the anticlines are finally condemned as of no value for oil. The dry holes do not necessarily prove that the anticlines do not contain oil, for many dry holes are drilled in and about any proved oil field.

PINE DOME.

The Pine dome, a large faulted dome forming Pine Mountain, 25 miles northwest of Casper, lies just south of the railroads and covers most of Tps. 34 and 35 N., Rs. 83 and 84 W. The dome is moderately

arched and shows fairly steep dips about the sides, but in a large area on the crest or top the strata lie almost flat. (See figs. 27 and 28.) The dome is limited on the east by the syncline between it and the Emigrant Gap anticline. On the northwest a wide cross sag south of Powder River station separates it from the Cottonwood Creek anticline, and a cross sag at South Casper Creek limits it on the south side from the minor anticlines north of Poison Spider Creek. The flat-lying variegated beds reach up on its west side.

This moderately arched dome forms the north end of a compound anticline that extends from Pine Mountain to Oil Mountain, trends N. 45° W., and parallels the Rattlesnake and Emigrant Gap anticlines. The general fold on which the Pine dome and Oil Mountain anticline are developed is one of the connecting folds between the giant anticlines of the Laramie and Bighorn Mountains, the other connecting fold being the Emigrant Gap anticline. The distance between the most northerly beds of the Pine dome and the most southerly beds of the Cottonwood Creek anticline, a fold situated upon the south limb of the Bighorn Mountain uplift, is but 3 miles. The relations of the dome to the Laramie uplift on the south are even closer.

The dips on the north, east, and south sides of the dome are low, ranging from 6° to 24°, but those on the southwest, west, and northwest are from 11° to 90° and some of the strata on the west side are even overturned as much as 22°. Because of these high dips the resistant sandstone and hard shale beds form about the dome encircling hogback ridges that are in places impassable, and the beds of soft shale between the sandstone give rise to narrow valleys that with the sandstone ridges are continuous around the dome except where all are faulted out on the west side, as shown in figure 28, or are cut by small dry canyons heading in the mountain. An overthrust fault on the west side has a throw of about 2,000 feet, and a similar fault on the northwest side has a throw of about 800 feet.

No oil seeps were seen in the Pine dome, though it is reported that oil has been gathered from a tunnel in sec. 27, T. 35 N., R. 84 W. When this tunnel was visited some dirty black water was flowing from it, but no traces of oil were seen. The Pine Dome Oil Co. is reported to have brought in during the summer of 1914 a 2,000,000-foot gas well on the east side of the mountain in sec. 36, T. 35 N., R. 84 W., close to the crest of the dome, and just below the gas water was obtained, presumably in the Tensleep sandstone, which is entirely sealed in this dome. The Cretaceous sandstones are all eroded from the crest, and consequently if oil in commercial quantities exists here it must be sought in older rocks, such as the Carboniferous. This question can be determined only by drilling.

ANTICLINE SOUTHWEST OF POWDER RIVER STATION.

About $2\frac{1}{2}$ miles southwest of Powder River station is a small open anticline involving at the surface the coal-bearing rocks that form prominent curved ridges of sandstone. Like other anticlines in this area it trends northwest. The axis presumably pitches at low angles at both ends, even though no formation completely encircles the anticline. The arch is limited on the east by a shallow syncline¹ that occurs between it and the Pine dome. The beds on the southwest side of the anticline dip from 25° to 72° , but the same beds on the east side dip 32° or less.

The Wall Creek sand, which is the principal oil-bearing sand at Salt Creek, is at least 3,000 feet and perhaps more than 4,000 feet below the surface on the crest of the arch. Because of the great depth of this sandstone, if for no other reason, the fold is not an attractive place to prospect for oil, although the facts that the Cretaceous oil-bearing sands are not exposed and that the anticline has a fairly large gathering ground in the great F L syncline suggest the possibility that it may contain oil.

COTTONWOOD CREEK ANTICLINE.

The compound anticline crossed by Cottonwood Creek, in Tps. 36, 37, and 38 N., Rs. 84, 85, and 86 W., is a minor upwarp on the south end of the great uplift of the Bighorn Mountains. It may be considered as a small southward-pitching anticline branching off from the margin of the greater anticline. The Cottonwood Creek anticline is in line with and probably was developed at the same time as the Pine dome and Oil Mountain anticline, which form a part of the fold that unites the Laramie and Bighorn uplifts. It is separated into two parts by a low cross sag which is followed by the perennial Cottonwood Creek in its eastward course just below the Desert ranch. To the north the limbs of the anticline gradually diverge and pass into the northward-rising beds of the Bighorn anticline. The axis of the northern part of the Cottonwood Creek anticline rises and is lost on the south end of the giant anticline of the Bighorn Mountains near the north side of T. 38 N., R. 86 W. The crown of the southern part of the anticline, in secs. 3 and 10, T. 37 N., R. 85 W., is shown by the tilted sandstone beds forming escarpments that dip away from this area. The part of the anticline south of Cottonwood Creek is short, as the area of sandstones in the middle is only about twice as long as wide, but, as shown in figure 29, the slightly dipping west limb continues across the flats to a point within a short distance of the railroad, where the dips increase rapidly, giving in

¹ Woodruff, E. G., and Winchester, D. E., Coal fields of the Wind River region, Fremont and Natrona Counties, Wyo.: U. S. Geol. Survey Bull. 471, p. 557, pl. 56, 1912.

effect a broad, low arch. Its axis trends in general northwest, but just west of Powder River, in the southwest corner of T. 37 N., R. 84 W., its direction is assumed with question to be east of north. The river crosses the extreme south end of the fold.

The strata on the east side of the Cottonwood Creek anticline dip 25° to 30° , much more steeply than those near the crown on the west side (6° to 10°), but not so steeply as those on the extreme west side (60° or more). In this respect the anticline is like those on the south and west sides of the field.

The Toltec well, in sec. 11, T. 37 N., R. 85 W., near the crown of the anticline, struck much warm sulphur water under considerable pressure at a depth of 915 feet, in the conglomerate which is shown on the stratigraphic section on Plate XXIII. The Cottonwood Creek anticline is likely to be barren of oil and gas because the upper oil-bearing sandstones are exposed at the surface, allowing opportunity for the oil to escape, and the lower sandstones and conglomerate are water laden.

BIG SULPHUR SPRINGS ANTICLINE.

The Big Sulphur Springs anticline, in Tps. 37 and 38 N., Rs. 83 and 84 W., is crossed by South Fork of Powder River and is one of the minor folds branching off from the Bighorn anticline. A cross sag followed by the river separates the anticline into two parts, one south of the river and the other on the slope of the Bighorn Mountains. The axis of the anticline is sinuous but in general trends northwest. South of Big Sulphur Springs the dips on the east flank are about 30° and those on the west flank about 5° ; south of the river those on the east limb are about 10° or less and those on the west from 1° to 4° , as shown in figure 30. This anticline differs from many of the other anticlines in this region in having low dips on the west limb and steep dips on the east. South of the river a small fault at right angles to the axis has a throw of some 300 feet, and the beds on the north side have moved up relative to those on the south side. The folding here is similar to that in the

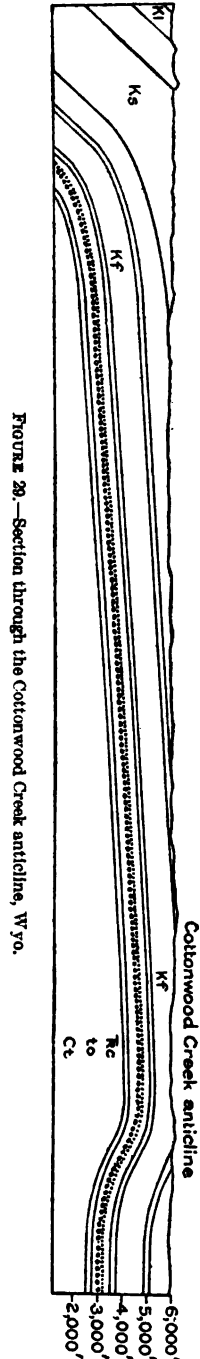


FIGURE 30.—Section through the Cottonwood Creek anticline, Wyo.

Cottonwood Creek anticline in trend and in that a small anticline is separated by a cross sag from the main uplift of the Bighorn Mountains.

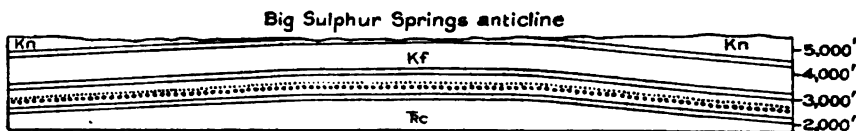


FIGURE 30.—Section through the Big Sulphur Springs anticline, Wyo.

The Big Sulphur Springs anticline is not considered favorable for the accumulation of oil and gas, because the conditions are similar to those in the Cottonwood Creek anticline, where the sandstones even near its crown contain water under pressure.

EMIGRANT GAP ANTICLINE.

The Emigrant Gap anticline is just west of Casper and trends about N. 45° W. from the Casper fault,¹ at the north side of the Laramie Mountains, to the Chicago & Northwestern Railway, a distance of about 20 miles. It is parallel to and about 10 miles east of the general anticline on which the Pine dome and Oil Mountain anticline are developed and with those uplifts forms a uniting fold between the giant anticlines of the Bighorn and Laramie mountains.² The anticline is much broader at the south end than it is at the north, as is indicated by the tapering outcrop of the formations involved in the sharp fold. (See Pl. XXIII.) Between this and the Big Sulphur Springs anticline there is a cross synclinal area which is the eastward continuation of the one at Powder River station, between the Pine dome and the Cottonwood Creek anticline. The axis of the Emigrant Gap fold is nearly in line with that of the Big Sulphur Springs anticline.

The dips of the beds on the narrow west limb of the Emigrant Gap anticline range from 40° to 70° and those on the east side near the axis from 8° to 30°, but farther east terrace-like structure is shown by the semicircular outcrop of the sandstones and shales in the southern part of the anticline (see Pl. XXIII), where the dips are as low as 1° to 7°, as shown in figure 31. The anticline is crossed near the middle by a cross sag that divides it into two parts. The southern part is the more pronounced because it is folded more, is eroded deeper, and is marked by prominent sandstone ridges, but it is the less attractive economically because nearly all the oil-bearing formations in it are exposed. The northern part has neither been folded so much nor eroded so deeply as the southern part and offers

¹ Hayden, F. V., U. S. Geol. Survey Terr. Fourth Ann. Rept., pp. 26-28, 1872.

² Idem, p. 28.

more inducement to prospecting, for some of the oil-bearing formations in it are sealed below shale. (See figs. 31 and 32.)

North of the cross sag which divides the anticline into two parts there are two minor upfolds on the main fold. They are indicated in the field by inclined beds of Frontier sandstone that form encircling ridges and escarpments. The southern one is dome-shaped and lies in secs. 19, 20, 29, and 30, T. 34 N., R. 81 W. The dips on the west side are about 70° , but those on the other sides are only 6° to 9° , as indicated in figure 32. On the crest of the dome the beds of sandstone are flat. A slight cross trough on the main



FIGURE 31.—Section through the south end of the Emigrant Gap anticline, Wyo.

anticline, on which is located the United States Geological Survey primary-control station in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 24, T. 34 N., R. 82 W., separates the dome from the northern one of the two minor upfolds. This cross trough, instead of being a topographic depression like most of such features, is an eminence rising 5,955 feet above sea level.

The northern one of the minor upfolds, an ideal fold for the accumulation of oil and gas in wet rocks, is in secs. 15, 22, 23, 24, 25, and 26, T. 34 N., R. 82 W. The dips on the southwest side average about 70° ; those on the northeast are about 8° . Because of this

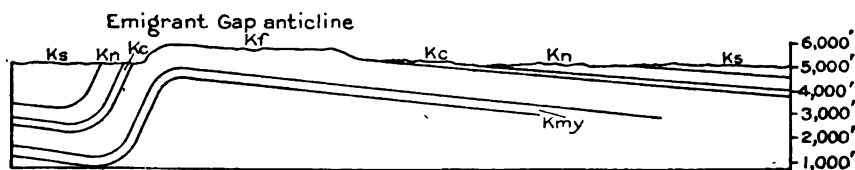


FIGURE 32.—Section near the middle of the Emigrant Gap anticline, Wyo.

great difference in the tilting of the beds the sandstones on the northeast side form a prominent, impassable southwestward-facing escarpment, but in contrast the same rocks on the southwest form only low hogback ridges. The crown of the anticline, in the SW. $\frac{1}{4}$ sec. 23, is shown by the outcrop of a hard shale, forming a slight hill in a large shale basin. This minor upfold is separated from the north end of the main fold by a slight cross trough near the corner of secs. 9, 10, 15, and 16, where the sandstones close over the principal arch. The crown of the north end of the main anticline is mostly confined to secs. 4 and 9, T. 34 N., R. 82 W., and sec. 33, T. 35 N., R. 82 W. The

dips on the west side of the north end of the Emigrant Gap anticline range from 30° to 50° , and those on the east side are 20° or less.

The Emigrant Gap anticline shows no oil seeps and has not been prospected except by two wells far down on its east limb, on Casper Creek, and by a shallow well in the SE. $\frac{1}{4}$ sec. 9, T. 33 N., R. 81 W., drilled in the summer of 1914 by the Monongahela Oil Co. The well last mentioned, which is near the axis of the anticline and near the cross sag that divides the fold into two parts, obtained a flow of strong sulphur water at a depth of 240 feet. The anticline merits consideration as a favorable fold for the accumulation of oil and should be prospected farther south, in the south-central part of of sec. 25, T. 33 N., R. 81 W., to test the Tensleep sandstone, which is about 1,000 feet below the surface; also farther north in secs. 9 and 23, T. 34 N., R. 82 W., and in the northeast corner of sec. 30, T. 34 N., R. 81 W., to test the Mowry shale, the Dakota sandstone, the Lower Cretaceous conglomerate, and possibly the Morrison formation, which are from 500 feet or less to 1,000 feet below the surface. The first wells should be drilled near the center of sec. 23, T. 34 N., R. 82 W., and if the formations named are found to be water-logged there it would probably be of little use to drill in the other localities in the northern part of the anticline.

NORTH CASPER CREEK ANTICLINE.

The North Casper Creek anticline, a simple fold in Tps. 36 and 37 N., Rs. 81 and 82 W., is about 22 miles northwest of Casper, between

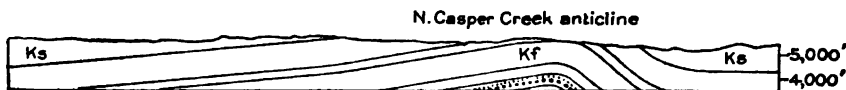


FIGURE 33.—Section through the North Casper Creek anticline, Wyo.

the old Hemmingway and Roseberry ranches. It is sometimes referred to as the Hemmingway dome. The anticline lies northeast of the Emigrant Gap anticline, and its trend is parallel to that of the other anticlines in this general region. Unlike most of these folds, it produces little effect on the topography because of the slight magnitude of the fold and because erosion has barely exposed one of the oil-bearing sands (the Wall Creek) on the very crown of the arch in the midst of Cretaceous shale.

In plan the formations crop out in elliptical bands about the anticline, the crest of which lies near the southeast corner of sec. 1, T. 36 N., R. 82 W., where the Wall Creek sand is exposed. As shown in figure 33, in transverse section the strata on the west side dip at angles of 8° or less, but east of the axis the dips are somewhat higher and in one place reach 45° . In a lengthwise section the axis is gently arched and pitches both northward and southward at angles of about 6° .

The steep dips on the east side are in harmony with similar dips on the east side of the Big Sulphur Springs and Castle Creek anticlines, but in contrast to the dips on the east side of the other anticlines in this area and those in the near-by Powder River¹ and Salt Creek² anticlines.

There are no oil seeps in the North Casper Creek anticline, and the three wells drilled about it struck considerable water in all the sandstones they encountered. However, an area about $4\frac{1}{2}$ miles long by $1\frac{1}{2}$ miles wide, or about two-thirds as large as the proved Salt Creek field, yet remains on the crown of the anticline, and it must be drilled before the presence or absence of oil can be fully determined. All the sands that show indications of oil in this field or adjacent fields, except the Teapot and the Wall Creek, are beneath the surface in this anticline. One or two deep wells drilled in sec. 1, T. 36 N., R. 82 W., would perhaps show whether this anticline contains oil, which the three wells drilled to the northwest of its crest have not conclusively done. These wells have shown that the sands in the lower parts of the anticlines are full of water, but other test wells higher up on the arch might strike oil or gas or both.

CASTLE CREEK ANTICLINE.

The Castle Creek anticline, an open fold in Tps. 37 and 38 N., Rs. 80 and 81 W., near the head of Castle Creek, is indicated on the ground by a westward-facing escarpment of Shannon sandstone, trending northwest across the west side of T. 38 N., R. 80 W., and a low northward-facing rim of the same sandstone on the north side of T. 37 N., Rs. 80 and 81 W. South of the 33 Mile ranch, in sec. 5, T. 37 N., R. 81 W., the escarpment fades away, owing to the greater softness of the sandstone and perhaps to its thinning. The axis of the fold, which trends northwest, may possibly represent the southward extension of the axis of the Powder River anticline,¹ and if so considered the axis as a whole is sinuous, like that of the Big Sulphur Springs anticline, with a sharp bend along the east side of T. 39 N., R. 81 W., to conform to the outcrop of the sandstones.

The strata on the east limb of the Castle Creek fold dip about 15° , and those on the southwest limb about 7° , as shown in figure 24. So far as observed there are no northward or northwestward dipping rocks in the Castle Creek fold, and thus the axis pitches gently southeast. For this reason none of the formations encircle the fold, and in this sense the anticline is at present incomplete.

The drill hole of the Midwest Oil Co., near the east quarter corner of sec. 31, T. 38 N., R. 80 W., is in a well-chosen locality near the

¹ Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, pp. 56-75, 1912.

² Wegemann, C. H., The Salt Creek oil field, Natrona County, Wyo.: U. S. Geol. Survey Bull. 452, pp. 37-83, 1911.

middle of the fold. It was sunk to a depth of about 2,000 feet and a little gas was obtained in the shale above the Wall Creek sand, but as this was the objective sand of the test well and as it was found to contain water drilling was stopped. Two wells have been started in sec. 28, T. 38 N., R. 81 W., but the first was abandoned before being finished and operations on the other, owned by the Casper Oil Co., which started in October, 1914, ceased in January, 1915, at a depth of 1,900 feet. This well is entirely in shale and has struck no oil or gas. No oil seeps were seen during the field examination, and none are reported as occurring here. The anticline may not contain oil or gas in commercial quantities, though it is situated only a few miles southwest of the Salt Creek oil field, the most productive field in Wyoming.

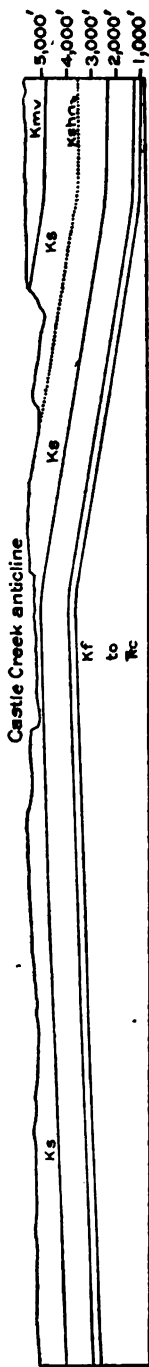


FIGURE 34.—Section through the Castle Creek anticline, Wyo.

POSSIBILITIES OF OBTAINING OIL.

From the results obtained by the wells already drilled in this field, which have cost at a moderate estimate over \$200,000, it would seem at first thought that the country should be condemned as oil territory and that further expenditure of large sums of money would be fruitless. But if oil and gas in Wyoming have accumulated according to the antinclinal theory, which demands, in water-saturated rocks, that they are forced to or toward the crowns of the anticlines, and as this theory applies to the productive Salt Creek and Bighorn Basin fields, then the anticlines in central Wyoming have not been thoroughly and properly prospected. Nearly all the wells have struck large flows of water in the several sands from the Wall Creek down to the Tensleep, and as these sands outcrop either in the mountains of this area or in those adjacent to it, it is highly probable that the sands in all localities, except possibly in the structurally higher parts of some of the anticlines, contain water.

The attention of those who may in the future prospect in this area should be directed toward the most promising places in the most favorable anticlines and away from those which on account of pitching only in one direction or on account of having been eroded too deeply are not favorable for the accumulation of oil or gas. There are a few anticlines in the area

in which possible oil-bearing sands are not exposed at the surface. As the rocks are charged with water under pressure, these places should be tested if further prospecting is attempted. The anticlines in which one or more of the oil-bearing formations—the Frontier sandstones, Mowry shale, Dakota sandstone, Lower Cretaceous conglomerate, Morrison and Embar formations, and Tensleep sandstone—lie within reach of the drill beneath thick shale beds are the North Casper Creek, Iron Creek, Emigrant Gap, and Oil Mountain anticlines, the minor anticlines north of Poison Spider Creek, and the anticline southwest of Powder River station. The most promising of these are the Emigrant Gap anticline (northern part), the minor anticlines between Poison Spider Creek and Casper Creek, the North Casper Creek anticline, and possibly the anticline southwest of Powder River station; and should these prove after thorough prospecting to be barren of oil, then the chances are against finding oil in the other anticlines of the area. The proximity of the North Casper Creek anticline to the proved Salt Creek dome suggests the possibility of there being an oil pool at this locality. The first two wells drilled in the summer of 1913 did not test the North Casper Creek anticline sufficiently to prove its character. As has already been pointed out, the wells are not located on the crown of the anticline, and two of them were drilled either only into the Wall Creek sand, which is exposed on the crown of the anticline, or only through the Frontier formation. There are no oil seeps from this sandstone where it is exposed on the crown of the anticline, and the negative results of drilling, taken in conjunction with the absence of oil seeps, prove conclusively that this sand, which is the chief oil-bearing sand of the Salt Creek field,¹ does not carry oil in the North Casper Creek anticline. The well drilled in the fall of 1915 by Mr. Fitzhugh and associates was farther up on the anticline and was sunk as deep as the Lower Cretaceous conglomerate and obtained water; therefore it has, with the other two wells, proved that a large part of the North Casper Creek anticline is barren of oil, and there remains only a few square miles of the highest part of the crown yet unprospected. Oil in this anticline may possibly be found in some lower sand, such as those in the lower part of the Frontier, the Lower Cretaceous conglomerate, or the Morrison formation, which lie 100 to 1,500 feet below the Wall Creek, or possibly the Tensleep, which is about 3,400 feet below the Wall Creek, or in some of the numerous intermediate sands. One or two wells drilled near the southeast corner of sec. 1, T. 36 N., R. 82 W., to a depth of

¹ Wegemann, C. H., The Salt Creek oil field, Natrona County, Wyo.: U. S. Geol. Survey Bull. 452, pp. 37-83, 1911.

about 3,500 feet, would possibly demonstrate whether this anticline contains oil.

Some of the same formations as those noted above are sealed below thick shale beds in the minor anticlines on the northern part of the Emigrant Gap anticline. The Mowry shale is the lowest formation exposed in them, and it is possible that the underlying sands, at depths less than 2,500 feet, may be oil bearing, especially as this part of the Emigrant Gap anticline is one of the nearest anticlines in the entire area to the great Powder River basin and hence has a large gathering ground for the accumulation of oil and gas. However, whether or not it contains oil can not be foretold prior to a test by the drill. Test wells should be located in secs. 9 and 23, T. 34 N., R. 82 W., and the first one should be drilled in sec. 23, which is the most promising part of the anticline.

Conditions similar to those in the northern part of the Emigrant Gap anticline exist in the minor anticlines north of Poison Spider Creek, and these anticlines should be tested near the SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 3 and the center of sec. 12, T. 33 N., R. 83 W., and possibly near the east quarter corner of sec. 18, T. 33 N., R. 82 W.

The formations from the Frontier to the Tensleep are below the surface of the Iron Creek anticline, and it is possible that the Mowry shale or some of the underlying sandstones or the conglomerate might contain oil or gas. A test well on Iron Creek within the inner sandstone rim would probably determine, if drilled to a depth of approximately 3,000 feet, whether or not oil is to be obtained in this anticline. The Mowry shale is about 500 feet below the surface, and the Lower Cretaceous conglomerate and Morrison formation would be reached at a depth of about 1,500 feet.

Likewise, the crest of the Oil Mountain anticline itself should be tested. Perhaps in this fold oil may be found in some sand like the Tensleep. A 1,500-foot well, properly located, would test the Tensleep sandstone in this anticline.

Attention should be paid also to the area southwest of the fault northwest of Oil Mountain, for this area is opposite the oil seep at the fault, and there is west of the fault an area of arched beds involving at the surface rocks as low as the Dakota. A well about 1,800 feet deep would possibly demonstrate whether or not the Lower Cretaceous conglomerate, the Morrison formation, and the Tensleep sandstone will yield oil in this place.

The Wall Creek sand is from 3,000 to 4,000 feet below the crest of the small anticline southwest of Powder River station, otherwise this fold might be considered favorably as a place to sink a test well.

Conditions similar to those in the Oil Mountain anticline exist in the south half of the Emigrant Gap anticline, where the Sundance formation occupies the crown of the anticline and the Tensleep sandstone



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is about 1,000 feet below the level of North Platte River. The Bates Hole anticline falls in the same class.

The Pine dome has been shown by the well of the Pine Dome Oil Co. to contain gas, and as the Tensleep sandstone is wholly sealed here, the dome looks hopeful.

The large quantities of asphaltum on Wallace Creek and its tributaries along the east front of the Rattlesnake Mountains naturally suggest that there is an oil pool somewhere to supply the asphaltum, unless, as is possibly the case, the rocks are so eroded as to have allowed all the oil to escape. It should be noted that these exceptional showings of oil along the mountains are almost directly opposite the Wallace Creek fold and that a line drawn from the middle of that fold to the exceptional seeps along the mountain would pass close to Phayles Reef, which is highly saturated with oil. These seeps may be in some way related to the Wallace Creek fold, where perhaps the oil is caught, but in this fold all the formations below the Teapot sand of the Mesaverde formation, which outcrops at Phayles Reef, are beyond the reach of the drill.

The United States Geological Survey can not state positively that oil or gas in commercial quantities exists in any of these anticlines, but it does suggest that some of them appear, after field examination, to offer favorable conditions for the accumulation of oil and gas. Drilling is the only method of ascertaining whether or not oil or gas can be found in these folds.



DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 641—J

**ANTICLINES IN THE BLACKFEET INDIAN
RESERVATION, MONTANA**

BY

EUGENE STEBINGER

**Contributions to economic geology, 1916, Part II
(Pages 281-305)**

Published January 22, 1917



**WASHINGTON
GOVERNMENT PRINTING OFFICE
1917**

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ANTICLINES IN THE BLACKFEET INDIAN RESERVATION, MONTANA.

By EUGENE STEBINGER.

INTRODUCTION.

The discovery of small quantities of oil and gas in several anticlines along the eastern front of the Rocky Mountains west of Calgary, Alberta, has aroused interest in the possible oil and gas resources of the formations in this general region, especially of the southern extensions of the folded and faulted beds that were productive in Canada. This interest has led to drilling for oil and gas at places within a few miles of the northern boundary of the Blackfeet Indian Reservation, on the west edge of the plains. A similar interest, in 1900-1902, led to drilling in the Cretaceous rocks at several places a few miles west of the west boundary of the reservation, close to the mountain front.

A report on the possibilities of finding oil and gas in a large area in north-central Montana east of the Blackfeet Indian Reservation has recently been issued,¹ and the Blackfeet Reservation itself, shown in figure 35, has now become the center of similar inquiries. The purpose of this paper is to give a brief account of the geologic formations in the reservation and of their lay or geologic structure, and a more detailed description of the anticlines and of the formations that appear to contain oil or gas in southern Alberta and northern Montana. An intelligent search for oil or gas in the reservation must be based on a knowledge of these geologic facts. Reports that describe coal² and low-grade iron ore³ and the general features of the geology of the reservation have already been published, and it is now considered desirable to summarize the facts bearing on the oil and gas prospects.

The general conditions in this region suggest that drilling in the Blackfeet Indian Reservation would have about the same chance of

¹ Stebinger, Eugene, Possibilities of oil and gas in north-central Montana : U. S. Geol. Survey Bull. 641, pp. 49-91, 1916 (Bull. 641-C).

² Stebinger, Eugene, Geology and coal resources of northern Teton County, Mont. : U. S. Geol. Survey Bull. 621, pp. 117-156, 1916.

³ Stebinger, Eugene, Titaniferous magnetite beds on the Blackfeet Indian Reservation, Mont. : U. S. Geol. Survey Bull. 540, pp. 338-342, 1913.

success as in the adjacent region in southern Alberta, extending from the international boundary northward to Calgary—a region in which drilling by over 40 companies during the last three years has been slightly successful. The similarity of the geologic features in these two regions may be summarized as follows:

1. The Colorado shale and the Kootenai formation, which yield most of the oil and gas so far found in southern Alberta and northern Montana, underlie the greater part of both regions.
2. The belt of folded and faulted strata along the front of the Rocky Mountains is continuous from one to the other of these regions, and in this belt the productive anticlines near Calgary and the folds in the Blackfeet Indian Reservation are both in places somewhat compressed and in others are associated with faults.

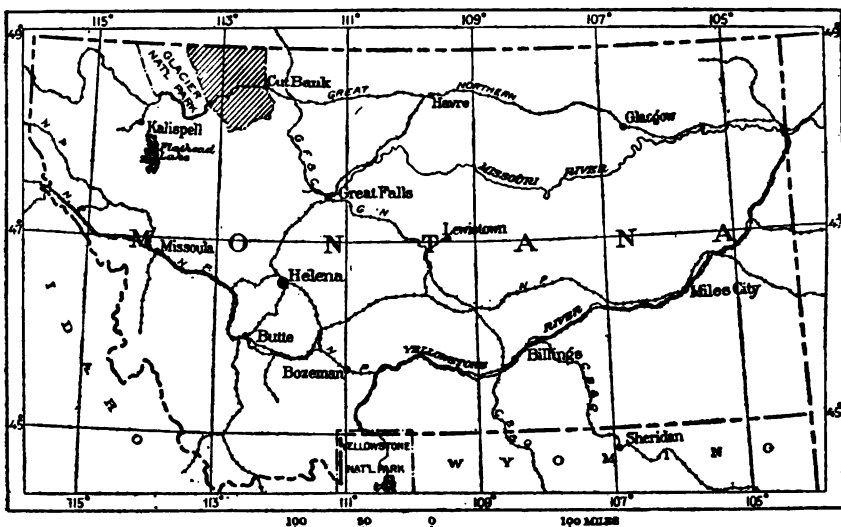


FIGURE 35.—Index map showing location of Blackfeet Reservation, Mont.

3. In the area east of the disturbed belt in both regions great thicknesses of nearly horizontal strata that have no strongly marked structural features, such as anticlines and synclines, overlie the possible productive formations.

LOCATION AND SURFACE FEATURES.

The location and area of the Blackfeet Indian Reservation are shown on the index map (fig. 35). The reservation lies wholly in Teton County, occupying nearly all its northern half, and contains about 2,425 square miles. The international boundary between Alberta and Montana forms its northern limit. The country is a gently sloping, nearly treeless plains region, which is everywhere easily accessible, presenting few obstacles to the construction of

railways or roads. The plains slope gently upward to the west to the base of the mountains, which rise abruptly without marked foothills. The average elevation of the plains districts ranges from 3,800 feet on the east edge of the reservation to about 5,000 feet near the base of the mountains. The mountains rise with wall-like abruptness from 4,000 to 5,000 feet above the general level of the plains.

The main line of the Great Northern Railway crosses the reservation from east to west. Cut Bank, Browning, and Glacier Park are the principal stations. Browning is the seat of the Indian agency for the reservation. Settlement on the Indian reservation has so far been limited almost entirely to its west half, where Indian ranches along the principal streams are devoted to the raising of horses and cattle. The extensive interstream stretches remain an open range, without fences or other improvements.

In the western part of the reservation, near the mountains, there are high, level plains, which comprise numerous isolated tracts, from a fraction of a square mile to 40 square miles or more in extent, and which are doubtless remnants of an older, almost perfectly formed plain. They are covered with a veneer of gravel, made up of kinds of rock found in the adjacent mountains, and have remarkably smooth surfaces and slope very regularly to the northeast, away from the mountains. Milk River Ridge and St. Mary Ridge are typical of the larger of these areas. Below these higher plains there are much more extensive lower plains, which, where best developed, also carry a veneer of gravel and slope evenly eastward, away from the mountains, to merge into the Great Plains. The best examples of the lower plains are Carlow Flat, an extensive and very evenly graded surface crossed by the Great Northern Railway west of Cut Bank, and the equally well developed plain between Cut Bank and Greasewood creeks, a few miles northwest of Browning.

FIELD WORK.

The field work on which this report is based was done by the writer alone, during a part of each of the field seasons of 1911, 1912, and 1913. The main object of the work was to classify the lands in the reservation with respect to their mineral value, and it was therefore necessary to make a regional examination of the geology and a close inspection of all possibly mineral-bearing tracts.

Good topographic maps were available for all the area examined and were used in the field as base maps on which to plot the geologic data. The land corners in all parts of the region are well marked and easily found. Iron pipes marking the boundaries of the lands allotted to the Indians have been placed at many of the corners.

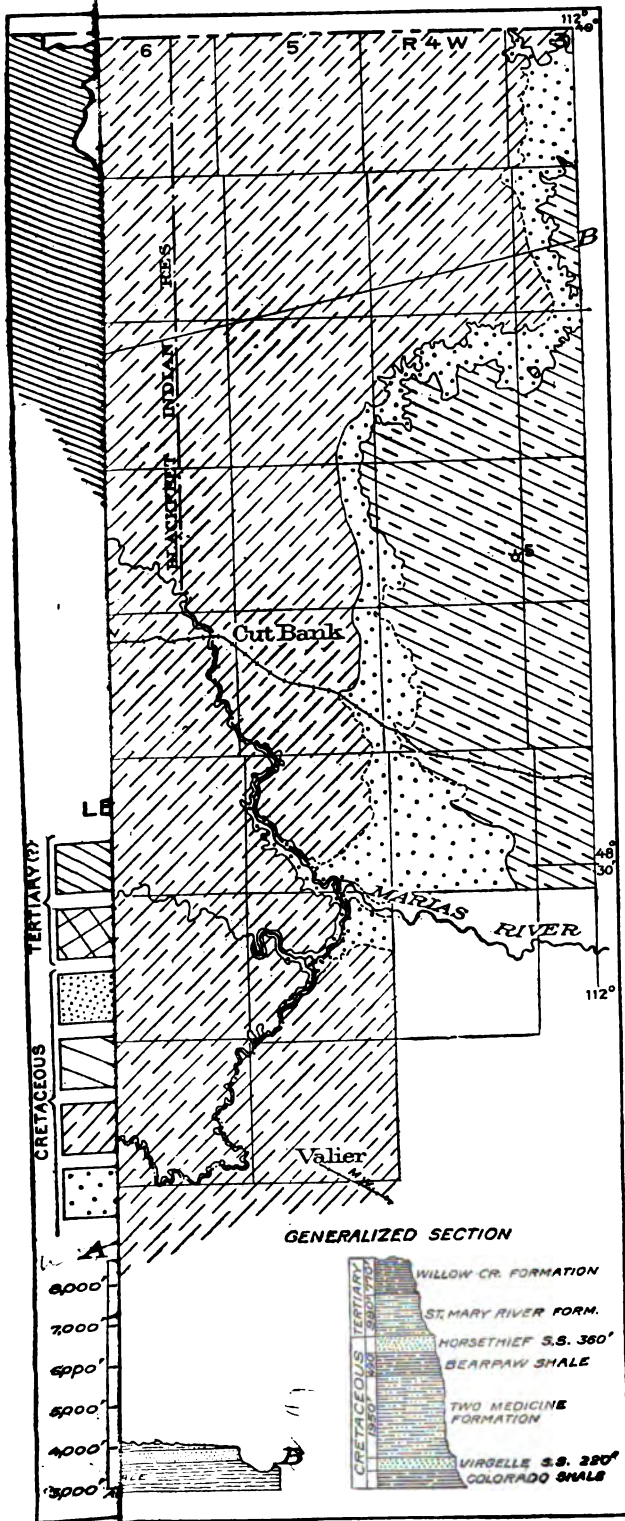
GEOLOGY.**STRATIGRAPHY.****GENERAL FEATURES.**

The geologic formations east of the mountains in the Blackfeet Indian Reservation are all sedimentary in origin and range in age from Lower Cretaceous to probably basal Tertiary. (See Pl. XXIV.) All the beds are apparently conformable and afford no evidence of break or disturbance between any of them or any indication of an interval of erosion. The sequence of the formations in the Upper Cretaceous part of the section is different from that so far described for any other locality in Montana, owing to the fact that in this region the marine invasion which is represented by the Claggett shale did not extend so far west as the present position of the Rocky Mountain front between latitudes 48° and 49° N. An account of these relations has already been published.¹

Two of the formations, the Colorado and Bearpaw shales, are unquestionably of marine origin and were laid down in separate epochs, during which a comparatively shallow sea covered the entire region. The remaining formations are mainly of continental origin—that is, they are irregularly bedded rocks that were for the most part deposited by streams and winds on land areas that were only slightly above sea level.

The succession of formations and the principal features of the rocks are outlined in the table on page 285.

¹ Stebinger, Eugene, The Montana group of northwestern Montana: U. S. Geol. Survey Prof. Paper 90, pp. 61-68, 1915.



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Formations occurring east of the mountains on the Blackfeet Indian Reservation, Mont.

System.	Series.	Group and formation.	Thickness in feet.	Character of the rocks.
Quaternary.	Recent.	Alluvium.		Deposits of small extent found along flood plains of the larger streams.
	Pleistocene.	Glacial drift.		Boulder clay, gravel, and lake silt and clay. Contains boulders and cobbles of granite, gneiss, quartzite, etc., transported from other regions. Deposits are of several stages not distinguished in this report.
Tertiary (?).	Eocene (?).	Willow Creek formation.	720+	Variegated clay and soft sandstone, chiefly maroon to chocolate-brown with subordinate gray, yellow, and greenish-gray beds. Fragments of fossil bones common. Clay in places contains thin lenticular beds of purplish-gray limestone. Forms a red soil over large areas. Top not seen.
		St. Mary River formation (coal bearing).	980	Alternating clay, clay shale, and soft sandstone; sandstone much cross-bedded and ripple marked. Colors gray to greenish gray; a few layers of clay are red. Contains a few thin lenticular limestones, many fragments of dinosaur bones, and fossil shells.
Cretaceous.	Upper Cretaceous.	Montana group.		
	Lower Cretaceous.	Kootenai formation.	2,000±	Gray sandstone and shale, alternating with maroon clay shale. Some of the sandstone massive. Conglomerate 6 to 50 feet thick near center. Carries a few leaves and fresh-water shells. Complete undisturbed section not found. May contain oil and gas in areas of favorable structure.

FORMATIONS THAT MAY IN PLACES CONTAIN OIL OR GAS.

Kootenai formation.—The Kootenai formation is the oldest formation seen in the plains portion of the Blackfeet Indian Reservation. It is exposed only in the belt of disturbed rocks adjacent to the mountains but underlies all the plains region. In this disturbed belt folding and especially thrust faulting have so greatly deformed the rocks that their exact sequence and thickness can not be determined, but the exposures are good and the general character of the formation is well known. A few miles beyond the west border of the area the Kootenai overlies a dark marine shale carrying Jurassic fossils. This relation, together with the fact that the Kootenai immediately underlies the Colorado shale, gives the formation approximately the stratigraphic position of the Kootenai of the Great Falls region, 150 miles to the southeast, which has in turn been correlated with the Kootenai formation of British Columbia and Alberta by means of the characteristic fossil plant remains, mainly leaves, found at both localities.

The Kootenai is composed essentially of alternating dark greenish-gray, black, and maroon shales and of gray sandstones that are in many places gritty and conglomeratic. A few beds of black carbonaceous shale and some thin streaks of coal are the only indications of coal found in the area, although to the north, in Alberta, and to the south, in the vicinity of Great Falls, the formation contains a large quantity of coal. An irregular bed of conglomerate, which is at some places as much as 50 feet thick, crops out at a horizon believed to be near the middle of the formation. Beds of sandstone, conglomerate, and grit, which must be considered the more likely reservoirs for oil or gas in the Kootenai, are distributed through it, generally in beds that range in thickness from 20 to 70 feet. Limestone in concretions and thin lenticular beds occurs sparingly in the shale.

The thickness of the Kootenai is not determinable at any point along its outcrop in the Blackfeet Indian Reservation because of its frequent duplication by faulting and because neither its base nor its top is anywhere visible. However, its minimum thickness can be determined by examining faulted blocks of the formation in which no duplication appears. Near Badger Creek (sec. 34, T. 30 N., R. 11 W.) 1,200 feet of beds that clearly belong to the Kootenai were measured in a single block of the formation that shows no repetition by faulting. On comparing this thickness with the measurement obtained in a well bored about 15 miles west of the reservation (see well log cited on p. 305), showing about 580 feet of beds that have been assigned to the Kootenai, it is evident that the formation becomes thinner toward the east in this region. At Great

Falls, where the Kootenai is best known in Montana, it is between 400 and 500 feet thick.

No escaping gas or residues or seepages of oil were noted at any point in the Kootenai formation in the area here described. Small quantities of oil and considerable flows of gas are reported from beds in Alberta that are believed to be equivalent to the Kootenai of this region. A small flow of gas was also obtained from sands in this formation in a well in the Sweetgrass district.

Colorado shale.—The next unit in the strata overlying the Kootenai formation in this region is the Colorado shale, a great body of bluish-gray to black shale containing sandstone beds in its lower half. This formation is about 1,600 feet thick in the eastern part of the Blackfoot Indian Reservation and underlies nearly all the area. It is of marine origin—that is, it was laid down on a sea bottom—and contains fossil sea shells in great variety. The rock deposited during this marine submergence continues northward into Canada and southward into Wyoming and beyond.

The Colorado shale seems to be the most probable source of oil and gas in this region. The only surface showings of oil so far found on the plains of northern Montana seep from the lower part of this formation, and pay sands that are either in the formation or are associated with it are found in adjoining areas both north and south of the State. The principal production from the Salt Creek field in northern Wyoming, and of all the fields in the Bighorn Basin comes mainly from the sands in the lower half of this group of rocks. The production of the important gas field at Bow Island, east of Lethbridge, in the province of Alberta, comes from the top of a sand that is supposed to lie immediately under this formation. This sand, however, is probably in the lower part of the Colorado shale. Likewise, as reported by Dowling,¹ a small production of high-grade oil from several wells in two anticlines lying southeast of Calgary, in the same Province, comes from sands at the same position with respect to this shale.

There are many exposures of the Colorado shale in the western part of the Blackfoot Indian Reservation, especially from Two Medicine Creek southward, in the belt of disturbed rocks, but the beds are invariably much crushed and crumpled. These crumpled beds of bluish-gray to black shale, which contain limestone in concretions and thin irregular beds, can not be measured, because they are at many places repeated by faulting, and therefore no accurate estimate of the thickness of this formation in the western part of the reservation can be made. The most extensive exposures appear along Two Medicine Creek from its junction with the South Fork in sec. 29, T.

¹ Dowling, D. B., Correlation and geological structure of the Alberta oil fields: *Am. Inst. Min. Eng. Bull.* 102, pp. 1360-1364, 1915.

31 N., R. 11 W., westward for 8 miles, to the vicinity of Glacier Park station. In this stretch continuous exposures show the shale crumpled and repeated by faults in a remarkable manner. The upper beds of the Colorado shale are exposed at the head of Marias River, on the eastern edge of the reservation in sec. 35, T. 32 N., R. 5 W., and from this point extensive exposures of the upper beds of the formation, which lie nearly horizontal, extend for many miles downstream. The log of a well (p. 305) which was drilled through these horizontal rocks near Kevin, about 15 miles east of the Indian reservation, shows 1,060 feet of shale which doubtless belongs to the Colorado. In addition to this thickness, about 580 feet of shale is exposed between the site of this well and the base of the overlying Virgelle sandstone, in the escarpment lying to the west, making about 1,640 feet in all. This is the only available estimate of the thickness of the formation in this region. According to the well record mentioned, three sandstones containing gas and water are reported from the lower part of the Colorado shale. As these sandstones are overlain by great thicknesses of shale they seem to be favorable receptacles for the accumulation and retention of oil and gas, which may have accumulated in them in commercial quantities in places where anticlines have permitted their concentration.

Additional evidence of the presence of petroleum in the lower part of the Colorado shale in this region was obtained by the writer during the summer of 1916 in the course of field work in the area adjoining the Blackfeet Indian Reservation on the south, extending across Teton County and into the northern part of Lewis and Clark County. The disturbed belt adjacent to the mountains in the Blackfeet Indian Reservation (see Pl. XXIV) continues southward across this area and, as in the reservation, affords many exposures of the Colorado shale, for the most part much folded and faulted. The lower part of this shale formation was found to be petroliferous in every extensive exposure for a distance of about 35 miles, extending from Dupuyer Creek to Sun River.

All the "showings" seem to occur at a single horizon in the lower part of the formation and are in the form of impregnations of a soft tarry bitumen along fracture planes in thin beds of impure limestone occupying a zone about 12 feet thick, in bituminous shale. The limestone is in beds as much as 8 inches in thickness. It has been irregularly fractured by the intense deformation in the disturbed belt, and the fractures are wholly or partly filled with calcite. The openings in the calcite veinlets thus formed are generally filled with a black tarry substance of high luster, readily soluble in carbon disulphide, and soft enough to flow when the thicker accumulations are tilted. A thin film of the bitumen is transparent, and it has a

deep brownish-red color. It is clearly an impregnation from a source outside the limestone, the distance the bitumen was able to travel along individual veinlets being readily determinable in many hand specimens. The shale inclosing these fractured limestone beds is a dark compact bituminous rock giving a distinct though transient odor of kerosene, especially after being gently heated. Hand specimens of this material yielded on distillation between 1 and 2 gallons of petroleum to the ton, and this shale is doubtless the source of the tarry material found in the limestone. The total thickness of this low-grade oil shale averages about 50 feet.

The horizon at which these bituminous limestones and shales occur is near the base of the thick body of shale making up the upper two-thirds of the Colorado shale in this region and just above its lower sandy portion, which contains as many as six sandstone beds from 10 to 50 feet thick intercalated with the shale and carrying *Inoceramus* and other marine fossils. The principal localities at which these bituminous rocks were noted are as follows: On the south bank of the Middle Fork of Dupuyer Creek, in the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 18, T. 27 N., R. 8 W.; on the South Fork of Dupuyer Creek, in the NW. $\frac{1}{4}$ sec. 36, T. 27 N., R. 9 W.; on the North Fork of Willow Creek, in the NW. $\frac{1}{4}$ sec. 9, T. 24 N., R. 8 W.; on Deep Creek, in the NW. $\frac{1}{4}$ sec. 28 and in sec. 16, T. 23 N., R. 8 W.; and on Sun River, in the SW. $\frac{1}{4}$ sec. 29, T. 22 N., R. 8 W.

No seeps or other indications of oil were found on the outcrops of the Colorado shale in the Blackfeet Indian Reservation. However, the only noteworthy showings of oil so far reported from northern Montana occur in the lower half of the Colorado shale. W. A. English,¹ of the United States Geological Survey, reports an occurrence on the north side of West Butte in the Sweetgrass Hills, a short distance south of the Canadian boundary. At this locality, in a spring on the Roscoe ranch near the line between secs. 11 and 12, T. 37 N., R. 1 E., there are slight showings of a light-greenish oil, which collects to the extent of about a teaspoonful in every 24 hours. Mr. English also reports that extraction tests made on samples from outcrops of the sandstone in the lower part of the Colorado on West Butte give a good show of oil. That the lower part of the Colorado shale in this part of Montana carries petroleum seems to be clearly proved by this occurrence.

Virgelle sandstone.—The Virgelle sandstone overlies the Colorado shale conformably. The transition from one to the other is marked by alternating beds of shale and sandstone lying between the characteristic rocks of the two formations. The principal member of the Virgelle formation is a thick bed of rather coarse-grained, massive

¹ English, W. A., personal communication.

sandstone which forms its upper half. In places it is much cross-bedded and contains large ferruginous concretions. At the mouth of Cut Bank Creek this formation is 220 feet thick. Near the center of T. 35 N., R. 4 W., it is 225 feet thick. Both these measurements were made on the eastern edge of the Blackfeet Indian Reservation and therefore do not apply throughout the reservation. The Virgelle was not measured along the outcrops in the disturbed belt of rocks, but in the west half of the area its thickness apparently does not differ greatly from that measured to the east.

The Virgelle sandstone contains large amounts of gas at Havre, Mont., along the axis of a folded and faulted uplift.¹ This formation is also gas bearing at Medicine Hat and other places in southeastern Alberta and may therefore contain oil and gas in this general region.

FORMATIONS ABOVE THE VIRGELLE SANDSTONE.

The succession of formations above the beds that may contain oil and gas in this region includes the Two Medicine formation, Bearpaw shale, Horsethief sandstone, St. Mary River formation, and the Willow Creek formation, presenting an aggregate thickness of about 4,400 feet of strata, composed of clay, shale, and sandstone. None of these beds has yet yielded favorable showings of oil or gas in southern Alberta and northern Montana. They have been drilled through in many places in southern Alberta with uniformly negative results except for small puffs of gas in rocks that are equivalent to the Two Medicine formation. The Bearpaw is a marine shale that is roughly equivalent to the upper part of the Pierre shale, which in Wyoming and Colorado, notably in the Florence oil field of Colorado, has yielded oil in commercial quantities.

The prospects for oil and gas in the formations above the Virgelle sandstone are meager, so the oil prospector is mainly interested in their thickness, the best available estimates of which are given in the table on page 285.

COMPARISON WITH CANADIAN CLASSIFICATION OF FORMATIONS IN SOUTHERN ALBERTA.

The general series of formations that occur in northern Montana extends northward into Canada. The changes in the Montana group and the thinning out and disappearance of the Claggett shale from east to west, which became apparent in the section of Montana, persist into southern Alberta, where they have been recognized by Dowling and are in every way similar. The differences in the for-

¹ Stebinger, Eugene, Possibilities of oil and gas in north-central Montana: U. S. Geol. Survey Bull. 641, pp. 49-91, 1916.

mation names used in Canada for the probable oil and gas bearing formations relate chiefly to the Colorado shale and the Virgelle sandstone, which the Canadian geologists have classified into three units, the Dakota sandstone, Benton shale, and Niobrara sands. The "Niobrara sands" are identical with the rocks described as Virgelle sandstone in this report. The fact that all the evidence afforded by fossils is adverse to the use of the name Niobrara for these sandstones was long ago emphasized by Stanton.¹

The Dakota has not been recognized in northwestern Montana at any point where the strata in which it should be present have been examined, and it is believed that its existence is equally uncertain in southern Alberta, where geologists have been inclined to assign to the Dakota any sandy beds that occur at its horizon. The sandstone beds at Bow Island, elsewhere referred to as Dakota, are probably the sandstones in the lower part of the Colorado shale, as stated in this report. It is very suggestive that well logs at Bow Island show dark shale beneath the pay sands called the Dakota. Marine fossils found in the basal sandstones of the Colorado shale in the section in central Fergus County in Montana seem to indicate the marine origin of all these sandstones, which are very similar to the productive sands in the Colorado shale in the oil fields of Bighorn Basin, Wyo. The use of the name Benton shale for shale overlying the supposed Dakota in southern Alberta is also inadvisable, for no evidence afforded either by fossils or lithology is important enough to warrant the recognition of the Benton and Niobrara divisions of the Colorado. The simple expedient of applying the term Colorado shale to strata in northern Montana, which include both Benton and Niobrara, has long been in use.

The Two Medicine formation, as well as the underlying Virgelle sandstone, when traced northward appears to be identical with the rocks known to the Canadian geologists as the Belly River series. In western Montana, however, the Virgelle sandstone is easily distinguished from the overlying rocks and has been mapped over considerable areas as a distinct unit, so that the term Belly River can not be conveniently used as a formation name in the area here described.

STRUCTURE.

EFFECT OF STRUCTURE ON THE ACCUMULATION OF OIL OR GAS.

It is generally conceded that the accumulation of oil in pools is due to some irregularity in the rock bed. If the beds lie flat or if they dip slightly but regularly in a certain direction, the oil that circulates through the pores of the rock will not tend to accumulate in any par-

¹ Stanton, T. W., and Hatcher, J. B., *Geology and paleontology of the Judith River beds*: U. S. Geol. Survey Bull. 257, p. 64, 1906.

ticular place, but if the beds have been disturbed—that is, bent into folds or broken—the oil may find a resting place and form a pool.

The structural form that is most favorable to the accumulation of oil is an upwarp or bulge, a feature that is generally known as an anticline, but if the anticline has about the same width as length it is generally called a dome. Other structural forms that are less favorable to the accumulation of oil are terraces, monoclines, synclines, or tilted blocks of rock that have been separated from the adjacent strata by faults. The degree of deformation of rock beds, however, varies greatly. In some places, as in the Kansas, Oklahoma, and Texas fields, it is so slight as to be imperceptible to casual inspection and requires close instrumental work for its detection; in others, as in the California and Wyoming fields, the tilting may be strongly developed, and can be ascertained at a glance by a trained observer.

The presence or absence of water in the “sands” is a further qualifying factor in determining the location of pools. The following statements concerning the presence of water have been verified again and again in developed fields:

1. If the pay sands are saturated with water, the gas and oil, which are lighter than the water, will be found above it in the crests of domes or anticlines or on the flats or terraces of monoclinical structures.

2. If only parts of the sands are saturated with water, the gas and oil will be found at the upper level of saturation, and this level may be on the crest of the anticline or may be part way down its sides.

3. If the sands are dry, the oil will have migrated downward either to the troughs of the synclines or to a point where further shifting has been prevented by the closeness of the sand.

4. If oil and gas occur in the same stratum, gas, which is the lighter substance, will generally, though not invariably, be found above the oil.

GENERAL FEATURES OF STRUCTURE IN THE BLACKFEET INDIAN RESERVATION.

The area described in this report can be divided into two large structural units, which differ greatly in the degree to which the strata have been deformed. A slightly curving line (shown on the geologic sketch map, Pl. XXIV), extending northward from a point on Birch Creek in T. 37 N., R. 9 W., to a point on the Canadian boundary in T. 37 N., R. 12 W., would mark a sharp transition from an area on the east in which the beds are nearly horizontal and undisturbed to an area on the west, adjacent to the mountain front, in which the rocks have been extensively faulted and folded. The eastern part of the area shown on the map is characterized by simple broad belts of out-

crop that trend regularly northward and the western area by a relatively complex arrangement of formations.

In the area where the beds are nearly horizontal they dip in general slightly westward at angles ranging from nearly 0° to 5° in gentle undulating folds whose average dip is not over 2° . As a result of this average westward dip of the bedrock formations the youngest or the highest stratigraphically, the Willow Creek formation, lies farthest west in these nearly horizontal beds, and the oldest, the Colorado shale, lies farthest east on the eastern edge of the tract. Thus one who is traveling westward up any of the principal valleys, as, for instance, from Marias River up Cut Bank Creek or Two Medicine Creek, would cross all the formations in sequence from older to younger in a distance of 35 to 50 miles. Between the south slopes of Milk River Ridge and the international boundary a broad, open syncline, whose steeper limb is on the west, lies on the west border of the area of nearly horizontal rocks. The axis of this syncline is between 1 and 2 miles east of the line that marks the transition to the disturbed belt of rocks and closely parallels that line. Farther north, in Alberta, this syncline broadens into a much more extensive feature, which reaches to Calgary and beyond. On the south it is practically coextensive with the outcrop of the Willow Creek formation and does not reach beyond Cut Bank Creek.

Minor undulations of the strata in the area of nearly horizontal rocks can be seen in detail only along the principal stream valleys. In places these undulations have produced structural terraces—that is, the general westward dip of the beds is interrupted locally by flats or benches. Elsewhere dips to the east in this area of generally westward-tilted strata indicate slight anticlinal folds. Both these types of structure may or may not have acted as reservoirs or traps for oil and gas if these substances were once in any of the underlying rocks. The areas occupied by these structures seem to be most favorable for obtaining oil and gas in the eastern part of the reservation. The detailed descriptions which follow treat of twelve structural terraces and anticlines that were noted in the course of the field work in the area of horizontal rocks. (See map, Pl. XXV.) The change in structure from the nearly horizontal beds in the eastern half of the reservation to the steeply dipping disturbed beds in the other half is very abrupt. Where exposures are good, especially along the major stream valleys, this change can be seen to occur within a few feet, there being no intermediate zone of gentle folds.

The belt of disturbed beds adjacent to the mountains that occupy the western third of the region here described is a small part of a structural area from 15 to 20 miles wide, which extends at least 80 miles southeast along the east front of the Rocky Mountains to and :

beyond Sun River and a much greater distance northwest across Alberta. Throughout this belt the rocks have been intensely folded and faulted by thrust stresses that acted from the southwest. In many places the individual formations are so much crushed and broken that it is impossible to identify them with certainty. The only constant feature in this whole disturbed area is the general northwesterly strike of the rocks. Because of this parallelism of strike the more resistant sandstones of the several formations appear as numerous strike ridges, and in many places the same hard beds are repeated by faulting within short distances. In the Blackfoot Indian Reservation the deformation of the disturbed belt accompanied the overthrusting that produced the Lewis overthrust, a great fault which can be traced along the eastern face of the mountains in the Glacier National Park, just off the west edge of the reservation.¹

The folds and faults in the belt of disturbed rocks along three well-exposed lines transverse to the general trend of the belt are shown graphically in the structural sections given on Plates XXIV and XXV. The only part of this area where large folds were formed lies along its eastern edge, which was farthest removed from the center of disturbance in the mountains. In the western two-thirds of this disturbed belt the beds are so much faulted and crushed that they could hardly serve as reservoirs for oil or gas. Large anticlines, which are described below, occur at seven localities along the east side of the disturbed belt.

DETAILS OF ANTICLINES AND STRUCTURAL TERRACES.

ANTICLINES IN BELT OF DISTURBED ROCKS.

Milk River anticline.—An anticline, here called the Milk River anticline, whose axis can be traced for more than 12 miles in the disturbed belt, extends northwestward across the south, middle, and north forks of Milk River. (See Pl. XXV.) This is the largest and apparently the most promising anticline in the reservation for prospecting for oil and gas in the belt of disturbed rocks. The Two Medicine is the lowest formation exposed in this anticline, and on its crest in each of the river valleys crossed all but about 300 to 500 feet of these beds have been removed by erosion, so that it is possible to explore the underlying Colorado shale and the upper part of the Kootenai formation by drilling to depths of not more than 2,500 feet. The best exposures in this large fold appear in the valleys of the forks of Milk River.

The northernmost outcrops of the Milk River anticline are in the valley of North Fork of Milk River, in the southwestern part of

¹ Willis, Bailey, Stratigraphy and structure of Lewis and Livingston ranges, Mont.: Geol. Soc. America Bull., vol. 13, p. 331, 1902.

T. 37 N., R. 12 W. The axis of the anticline at this locality is fairly well defined and extends through secs. 31 and 32, cutting the section line between these two sections about 1,500 feet north of the quarter corner. The dips on the east limb of the fold are best exposed in the N. $\frac{1}{2}$ sec. 32, where there are a series of outcrops of sandstone and shale whose structure can be accurately determined. The dips in this tract range from 30° to 51° NE. The west limb of this fold is less steeply tilted than the east limb, so the anticline is somewhat unsymmetric. About 1,500 feet west of the east quarter corner of sec. 31 the beds exposed dip to the southwest at an angle of not over 4° . Farther west on North Fork of Milk River the Two Medicine beds are continuous for about $1\frac{1}{2}$ miles upstream, the westward dip apparently continuing through all this stretch to the W. $\frac{1}{2}$ sec. 36, where the overlying Bearpaw shale enters in normal sequence and it in turn is overlain by the Horsethief sandstone, with its characteristic oyster beds. The stratigraphic sequence here shown seems to prove conclusively that the beds exposed along the crest of the Milk River anticline at this point belong to the Two Medicine formation. In sec. 6, T. 36 N., R. 12 W., numerous exposures in a tributary coulee to Milk River also show the westward-dipping rocks on this fold. The low dips on the west limb of this anticline near the axis of the fold again appear at this point, where they are only 7° to 8° , but farther west the beds are inclined at angles as great as 51° .

The northward extension of the Milk River anticline is apparently interrupted by a cross fault, which trends about N. 80° E., cutting through the S. $\frac{1}{2}$ secs. 29 and 30, T. 37 N., R. 12 W., and extending westward into the adjoining township. In the W. $\frac{1}{2}$ sec. 29 the dips, instead of being to the east, as they would be if the east limb of the Milk River anticline continued through this locality, are to the west, the maximum angle being 60° . From this locality westward the dips are all to the west, but instead of the low dips of 4° seen on the west limb of the Milk River anticline—the dips that would appear normally in this position on the fold—the dips are as great as 60° . The lack of accordance of dip in this tract with that in the area to the southeast, along the anticline, seems to prove that the anticline does not continue through this area but has been interrupted by faulting. About 6 miles farther northwest, however, on St. Mary River in Canada, a broad anticline occurs almost exactly on the prolongation of the axis of the Milk River anticline. This is doubtless an extension of the same fold.

The rocks south of the exposures on North Fork of Milk River are very poorly exposed for about 5 miles, but in the valley of Middle Fork of Milk River, in the south half of T. 36 N., R. 12 W., the anticline is again exposed and its axis, which is fairly well

defined, passes through secs. 22, 27, and 34 with a slight curve. Here, as on North Fork of Milk River, the fold is not symmetric, the steeper limb being on the east. Near the center of sec. 22, about 1,500 feet east of the crest of the fold, a dip of 56° NE. was noted. About 2,000 feet southwest of this locality the dip is 4° SW. A quarter of a mile farther southwest it has increased to 18° , and it gradually becomes steeper until in the N. $\frac{1}{2}$ sec. 29 the strata are tilted at an angle of about 40° , and again the dark marine shale of the Bearpaw is overlain by the Horsethief sandstone in normal succession. In this area on the whole the succession of the strata and the character of the folds are identical with those in the area to the northwest and seem to prove conclusively that the Milk River anticline is continuous through the intervening area.

On the south side of the valley of Middle Fork of Milk River the dips outline a fold that is also in harmony with the structure to the north. In secs. 33 and 34 southwestward dips of 24° to 34° are noted, and the Bearpaw shale and Horsethief sandstone enter in normal succession above the Two Medicine formation. The crest of the fold, however, is more compressed than it is to the north, the dips near the north line of sec. 34 being in opposite directions, those on the west having an angle of 58° and those on the east an angle of 65° . Throughout the W. $\frac{1}{2}$ sec. 34 and in the E. $\frac{1}{2}$ sec. 35 dips of 27° to 44° were measured at a number of points, indicating that in this locality the east limb remains much as it is farther north. In the SE. $\frac{1}{4}$ sec. 26, however, there are several small cross faults, which are indicated by westward dips of about 25° throughout about 50 acres. This is the only cross fault noted on this anticline. Others are probably present and must be considered in prospecting for oil or gas.

In T. 35 N., R. 12 W., the axis of the Milk River anticline is still well outlined by opposite dips in the Two Medicine formation. The anticline continues southward beyond South Fork of Milk River through secs. 2, 11, and 14, and probably as far as the south side of sec. 25. In secs. 3 and 4 the westward dips are much the same as those farther north on Middle Fork. Near the center of sec. 15 of the same township the Horsethief sandstone, which lies on the continuation of its exposures to the north and dips about 30° W., indicates that the fold still continues in this locality. South of Milk River a few exposures of the same sandstone in sec. 26 show that the anticline is continuous for at least a mile south of South Fork. This fold, however, if extended farther south meets the extensive gravel-covered area that forms Milk River Ridge. On the south slope of this ridge, in secs. 8, 16, 17, and 18, T. 34 N., R. 11 W., on the line of the trend of the Milk River anticline, the exposures are fairly good and indicate no anticlinal structure, the beds all dipping westward. At this place, therefore, there is probably a cross fault

like the one that limits the Milk River anticline on the northwest, as already described. The southern limit of this fold must consequently remain indefinite, as the surface indications do not prove its existence for a distance greater than a mile southwest of Middle Fork of Milk River. All told, this anticline can be followed for about 12 miles, and is the largest single fold found in the Blackfeet Reservation. The lowest stratigraphic horizon reached along its crest, and therefore the position that is nearest to the underlying, possibly productive sands in the Colorado shale and Kootenai formation, is in the bottoms of the valleys of the major streams crossed by the axis of the fold. These localities include parts of secs. 31 and 32, T. 37 N., R. 12 W.; secs. 27, 34, and 35, T. 36 N., R. 12 W.; and secs. 2, 3, 11, 13, and 14, T. 35 N., R. 12 W. The most favorable locations for drilling appear to be in these sections. Because of the high dips in the east limb of the fold it seems best to drill on the west limb, near the axis of the anticline.

South Fork anticline.—A large fold, the second in size and probably in value as a possible reservoir of oil or gas, lies east of and parallel to the Milk River anticline and can be traced for about 6 miles across the principal branches of South Fork of Milk River in T. 36 N., Rs. 11 and 12 W., and in T. 35 N., R. 11 W. For convenience of description in this report this fold is described as the South Fork anticline.

This anticline is the only extensive one in the belt of disturbed rocks on the reservation which is not bounded on both sides by faults. It is bounded on the west by a fault along its entire length, but the beds on the east extend into the area of nearly horizontal rocks without a break. The desirability of prospecting in this anticline, however, is somewhat uncertain because of the great thickness of rocks that overlies the possible oil and gas sands. At least 400 feet of the beds of the St. Mary River formation occur at the lowest stratigraphic point on the crest of the fold, so that the depth to the Virgelle sandstone is over 3,000 feet and the depth to the base of the Colorado shale is nearly 5,000 feet. However, if other anticlines in this region should prove productive drilling might be done on this fold. On Middle Fork of Milk River the South Fork anticline is best exposed along the south side of the valley in sec. 36, T. 36 N., R. 12 W., and sec. 31, T. 36 N., R. 11 W. The crest can be located only approximately between the eastward dips along the west line of sec. 31 and the westward dips, which occur about 2,000 feet to the west in sec. 36. The exposures on the north side of the valley are very poor, and the continuation of this anticline northward can not be proved from the surface indications.

Between South Fork and Middle Fork of Milk River the area in a line prolonged from this fold affords only a few exposures, but

on South Fork of Milk River the anticline is again indicated by opposite dips in the cut bank along the south side of that stream. Near the center of sec. 8 the dip in the Willow Creek formation is 16° NE., which accords very well with the dip of 18° along the same line of strike on the Middle Fork. In the NW. $\frac{1}{4}$ sec. 17, close to the west line of the section, the rocks are tilted 30° SW., the anticlinal axis cutting through the W. $\frac{1}{4}$ sec. 8 apparently in close alignment with the trend of the fold as outlined on Middle Fork of Milk River.

The southward continuation of the South Fork anticline is very indefinite, the area south of the river affording few exposures from which its position can be determined. On the south side of Milk River Ridge, along the line of *C-D* on Plate XXV, the crest of a fold lying close to the fault block that bounds the Blackfeet coal field on the east probably represents a southeastern extension of this anticline, but if so its axis in this area has shifted westward to a point nearer the fault just mentioned than it is in the area farther north. The lower part of the Willow Creek formation outcrops on the axis of the fold at this locality.

Blackfeet anticlines.—A fault block lying between the Milk River and South Fork anticlines and extending southward beyond the limits of those folds contains rocks that are closely folded, for the most part in two parallel anticlines. Coal is exposed on the flanks of these folds for about 12 miles along the fault block, and the area has been described in a previous report as the Blackfeet coal field.¹ Sections *A-B* and *C-D* (Pl. XXV) intersect these folds and give a general idea of their relations to the surrounding structural features. They seem to offer little chance of finding oil or gas, because the faults on both sides probably limit the area which could serve as collecting ground for oil or gas. Wells drilled at the lowest stratigraphic points on these folds to the highest possibly productive sand would have to extend through nearly all the Bearpaw shale in addition to the full thickness of the Two Medicine formation, a depth of nearly 2,500 feet, and would reach the base of the Colorado shale at a depth not much less than 4,000 feet.

Anticlines on Cut Bank Creek.—On Cut Bank Creek, about 2 miles west of Cut Bank School, in secs. 10, 11, 14, and 15, T. 33 N., R. 11 W., there are two parallel anticlines whose axes trend about N. 18° W. The western of these two folds is closely compressed, the dips on the west limb being as high as 70° and those on the east about 60° , the axis intersecting a point very close to the southwest corner of sec. 11. The axis of the east fold crosses the creek in the southwest quarter of the same section. The anticline there is much more open than the one

¹ Stebinger, Eugene, Geology and coal resources of northeastern Teton County, Mont.: U. S. Geol. Survey Bull. 621, pp. 148-153, 1916.

to the west and exposes the Bearpaw shale along its crest, as indicated by the cut-bank exposures on either side of the creek. The east limb of this fold near the axis, on the south side of the creek, has a dip of about 20° . The west limb, on the north side of the creek, has a dip of about 37° , and the St. Mary River formation appears in normal succession above the Horsethief sandstone, which in turn lies above the Bearpaw shale. The rocks exposed in the west fold at this point are identical with those of the St. Mary River formation and apparently belong to that formation, as is shown by the sequence just cited and by the absence of indications of faults between these two folds.

Anticline on Two Medicine Creek.—In the valley of Two Medicine Creek, near the mouth of Little Badger Creek, in secs. 22 and 27, T. 31 N., R. 10 W., there is an anticline which lies between steeply dipping faulted beds on either flank. The axis of this fold can be located approximately by opposite dips on the north side of the valley, in the NE. $\frac{1}{4}$ sec. 22. Near the center of this section the strata dip 30° SW., whereas about 2,000 feet to the east similar beds are tilted 64° NE., this steep dip continuing to the faulted ground in the W. $\frac{1}{4}$ sec. 23. The exposures clearly indicate a moderately compressed fold, as shown on cross section *E-F* (Pl. XXV), but it was impossible to determine the formation to which the beds belong. Their lithologic appearance indicates that they can be assigned either to the St. Mary River or the Two Medicine formation, but as the rocks are not in normal sequence and the fossil shells and dinosaur bones found in them are indeterminate, it is not yet possible to decide this question.

Anticline on Badger Creek.—On Badger Creek, in the east half of T. 30 N., R. 10 W., there is a fairly open fold which exposes the St. Mary River formation along its axis. The axis trends about N. 15° W. and is fairly well defined on both sides of the creek. Its northwest and southeast limits, however, are indefinite because of the cover of glacial drift, which conceals the rocks in the upland areas on both sides of the valley. The dips on the east limb of this fold range from 15° to 30° and those on the west limb from 30° to 60° . Beds of sandstone in the St. Mary River formation arch over the crest of the anticline and are strikingly shown on the north side of the valley. The small size of this fold and the great depth to the underlying sands that may contain oil or gas seem to offer comparatively little inducement for prospecting.

ANTICLINES AND STRUCTURAL TERRACES IN THE AREA OF NEARLY HORIZONTAL ROCKS.

Anticline on North Fork of Milk River.—In T. 37 N., R. 11 W., there is an anticline in very gently folded rocks whose axis passes through secs. 17, 20, and 21, but can not be more definitely located.

The dips that outline this fold are exposed only along the sides of the valley of North Fork of Milk River. Near the center of sec. 16, on the northwest side of the valley, the beds dip $1\frac{1}{2}^{\circ}$ NW. The strata southwest of this point lie horizontal, as is shown by exposures on both the north and the south side of the river. The west limb of the fold is indicated in the SW. $\frac{1}{4}$ sec. 20 by dips of about 2° SW. The strata southwest of this point lie horizontal, as is shown by exposures on both the north and the south sides of the river. The west limb of the fold is indicated in the SW. $\frac{1}{4}$ sec. 20 by dips of about 2° SW.

The strata exposed in the vicinity of this anticline belong to the Willow Creek formation, and a well drilled to the nearest productive sand yet found in this region would necessarily penetrate all the intervening strata between the Virgelle sandstone and the Willow Creek rocks, which would include all of the St. Mary River formation, Horsethief sandstone, Bearpaw shale, and Two Medicine formation—a total of nearly 4,000 feet, in addition to an undetermined thickness of Willow Creek beds—probably about 500 feet. The extension of this fold can not be certainly determined from the surface exposures, as the outcrops of the bedrock formations away from the river valley are very meager. In the valley of South Fork of Milk River, in secs. 27 and 28 of the township adjoining to the south, and nearly on the line of strike, there is no anticline, as the beds dip continuously westward.

Anticline on Cut Bank Creek.—On the south side of the valley of Cut Bank Creek, in sec. 34, T. 34 N., R. 9 W., exposures indicate a gentle anticline whose axis extends north-northwestward, the axis lying approximately along the center of the valley of Willow Creek, which at this point enters Cut Bank Creek from the south. The Bearpaw shale is the surface formation on the fold. In the W. $\frac{1}{4}$ sec. 34, in a steep bank on the south side of the creek, the clay shale beds belonging to this formation dip westward at an angle of about 2° . On the east side of the same section beds of similar shale dip eastward at an angle somewhat under 1° . This fold does not reach as far north as the south edge of Rimrock Butte, near the center of this township, as is indicated by excellent exposures of the rocks, which show a uniform westward dip. The southward extension is indefinite because of the poor exposures along the lower part of the valley of Willow Creek. Nearly the full thickness of the Bearpaw shale is exposed along the crest of this fold on Cut Bank Creek, and the overlying Horsethief sandstone lies above the shale less than 1 mile to the west. The depth here to the top of the Virgelle sandstone is about 2,400 feet.

Anticline on Willow Creek.—On Willow Creek, in secs. 8, 16, and 17, T. 33 N., R. 9 W., there are excellent exposures of the crest of a

broad, gentle anticline outlined by dips for several miles along the valley of the creek. The east limb of the fold shows dips as great as 4° on the south bank of the creek, near the north line of the section, in the NW. $\frac{1}{4}$ sec. 16. A few hundred yards to the west the beds have flattened to a dip of only $\frac{1}{2}^{\circ}$, and where the creek crosses the line between secs. 16 and 17 the beds are horizontal. The next exposures to the southwest, along the valley of the creek, show rocks that are tilted uniformly at an angle of about 2° SW. for about 1,500 feet, as far as the exposures continue. The dips indicate that an anticline extends in a northwestward direction across the creek near the line between secs. 16 and 17. Nearly the full thickness of the Horsethief sandstone is exposed along the crest of this anticline, so that in order to reach the underlying Virgelle sandstone the drill would have to penetrate about 2,700 feet of rocks.

Small structural terraces on Two Medicine Creek.—On the lower part of Two Medicine Creek there are four localities where a flattening of the dip in beds that are generally inclined westward produces small structural terraces. At each locality these features can be seen only in the badland exposures along the sides of the valley of the creek, the north and south extent of the structural terraces being indeterminate because of the lack of exposures. In the N. $\frac{1}{4}$ sec. 4, T. 31 N., R. 6 W., the rocks of the Two Medicine formation lie horizontal, and the flat or terrace structure apparently continues northward through the center of sec. 33. Near the east line of the section the beds dip about 2° W., and near the center of sec. 3 they again lie practically flat over an area of several hundred acres. Still farther east, in sec. 2, these beds dip westward, and this dip continues for several miles downstream. The dips therefore seem to show the presence of two small structural terraces, which are indicated on the map (Pl. XXV). Three miles to the southwest, in secs. 11 and 12, T. 31 N., R. 7 W., there is another structural terrace. In the W. $\frac{1}{4}$ sec. 12 the beds lie nearly horizontal. In the E. $\frac{1}{4}$ sec. 12 they dip about $1\frac{1}{2}^{\circ}$ W. and then flatten in the E. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 11, west of which they again assume the uniform westward dip which continues for many miles up the valley of the creek. These four structural terraces on the lower part of Two Medicine Creek are all in the lower half of the Two Medicine formation. The eastern pair of terraces is probably not more than 400 or 500 feet above the top of the Virgelle sandstone, whereas the two farther west lie nearly 1,000 feet above the Virgelle.

Structural terraces in Tps. 29, 30, and 31 N., R. 9 W.—Between Badger Creek and Two Medicine Creek, in secs. 29 and 32, T. 31 N., R. 9 W., and secs. 5 and 8, T. 30 N., R. 9 W., there is a structural terrace that occupies about 3 square miles. In secs. 21, 22, and 28

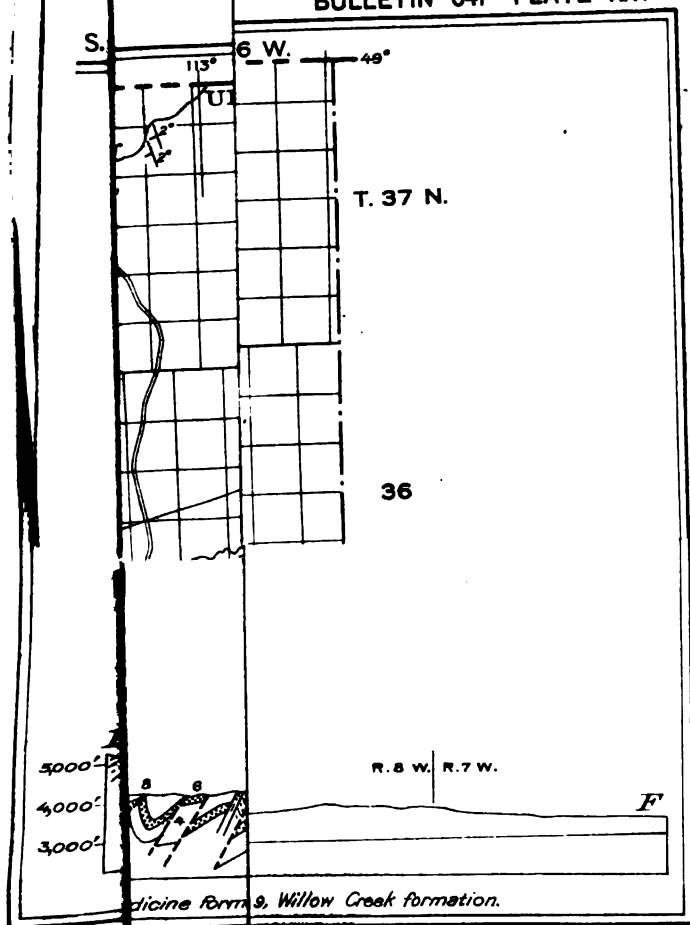
the Horsethief sandstone and St. Mary River formation are fairly well exposed and dip uniformly 2° SW. Toward the southwest these inclined beds flatten first to a dip of about $\frac{1}{2}^{\circ}$ in the NE. $\frac{1}{4}$ sec. 29 and then to practical horizontality near the center of the section. The flat-lying beds, as indicated by exposures of rocks in the coulees, extend southeastward in a belt that reaches nearly to Badger Creek. The southward extent of this structural terrace could not be definitely ascertained, because the exposures along Badger Creek, on what appears to be its trend, are very poor. In secs. 7 and 8, T. 30 N., R. 9 W., on the north side of Badger Creek valley, the Horsethief sandstone dips 1° W., and this dip is probably the continuation of the general westward dip on the west side of the structural terraces referred to. Farther north, in sec. 19, T. 31 N., R. 9 W., in the line of strike of the inclined strata last mentioned, the rocks dip as much as 3° NE., and this dip suggests that the horizontal strata near the center of sec. 29 occupies the basin of a shallow syncline. Farther south the dips, however, clearly indicate the presence of the structural terrace. Nearly the full thickness of the Horsethief sandstone and a few feet of St. Mary River beds appear at the surface in this terrace.

In an area of about 3 square miles that lies at the south edge of T. 30 N., R. 9 W., and extends southwestward into the adjoining township, there seems to be a second structural terrace. The beds lie flat throughout all of sec. 34 and parts of the adjoining sections, and exposures in the N. $\frac{1}{2}$ sec. 10, T. 29 N., R. 9 W., indicate that this area of horizontal rocks extends at least that far south. To the west, as indicated by the numerous dip symbols shown on the map (Pl. XXV), the rocks dip uniformly to the west. Dips of 4° to 5° in sec. 9 of the same township, together with those of 2° to 3° in sec. 32, T. 30 N., R. 9 W., indicate that the beds are uniformly tilted to the west on the west side of this structural terrace. In the SW. $\frac{1}{4}$ sec. 26 a dip of 7° NE. was noted, which suggests that there is at that locality a sharp reversal of the normal southwestward dip.

Anticlines on Blacktail Creek.—In the valley of Blacktail Creek, in the southeast quarter of T. 30 N., R. 8 W., a gentle fold is clearly outlined in the upper part of the Two Medicine formation. The dip of the beds on the west side of this fold is in places as great as 8° , and many exposures show that the beds are uniformly tilted to the west for a distance of about 4 miles along the side. The dip of the beds on the east side of the fold is lower but equally persistent. Flat beds were noted in the W. $\frac{1}{2}$ NW. $\frac{1}{4}$ sec. 28, and the axis of the fold that extends in a northwest direction crosses near this locality. In order to reach the base of the Colorado shale on the crest of this fold the drill would have to penetrate about 3,800 feet of rocks. The

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BULLETIN 641 PLATE XXV



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southeast extension of the anticline just described can not be accurately determined because of the lack of exposures in the level areas southeast of Blacktail Creek. Where the extension of this fold should cross Birch Creek the exposures are also very poor, and no definite indications of an anticline were noted.

Rocks dipping in opposite directions on Blacktail Creek, near the north quarter corner of sec. 13, T. 29 N., R. 9 W., indicate a narrow-crested fold extending in a direction about N. 15° W. The dips on the east flank are about 1° and those on the west flank about 2°. Bearpaw shale outcrops along the crest of this fold.

Anticlines on Birch Creek.—There is a small, narrow-crested anticline on the west edge of the area of nearly horizontal rocks on Birch Creek, in secs. 4 and 9, T. 28 N., R. 9 W. This fold is exposed only along the sides of the creek in outcrops near water level. The beds on the west limb of the anticline dip between 8° and 10° and to the southwest are cut off sharply by a fault within half a mile of the axis of the fold. The beds on the east limb dip about 1°, thus showing a decidedly unsymmetric fold with a steep flank on the southwest. The St. Mary River formation is exposed on the crest of the anticline and at water level along the creek there are a few feet of the Horsethief sandstone.

Two miles farther up Birch Creek fairly good exposures indicate a second anticline, whose axis, which trends N. 12° W., crosses the creek about 900 feet west of the line between secs. 17 and 18, T. 28 N., R. 9 W. The Bearpaw shale and Horsethief sandstone are exposed along the crest of the fold, and on the west flank a considerable thickness of the St. Mary River formation overlies the Horsethief. This anticline is also unsymmetric, but the steeper flank is on the northeast, the dips approaching the vertical. On the southwest side for a mile from the axis the dips do not exceed 30°, and for nearly half this distance the beds dip gently at angles not much over 8°.

RESULTS OF DRILLING.

No drilling had been done on the Blackfeet Indian Reservation up to the time of the preparation of this report. Borings, however, have been made on the east, north, and west sides of the reservation, all of them with negative results. These borings suggest that in this region it is useless to drill either in highly faulted rocks, such as those in the west half of the disturbed belt near the mountain front, or in areas where the rocks lie very flat.

The only well so far drilled on an anticline near the reservation was located near the crest of a large fold on the line of the Milk River anticline, on St. Mary River about 1½ miles north of the boundary (locality 4, Pl. XXIV). Information concerning this boring,

which was drilled since the writer examined the region, was kindly furnished by Dr. James S. Stewart, of the Geological Survey of Canada. Only a few hundred feet of the upper part of the Colorado shale were penetrated according to latest reports, and therefore the boring can not be considered a fair test of the possibility of obtaining oil along this fold. The boring was made with a diamond drill and reached the Colorado shale at a depth of about 300 feet, after passing through the sandy beds of the lower part of the Two Medicine formation and the Virgelle sandstone. By September, 1915, the drill had reached a depth of 560 feet, and operations were suspended. The shale at the bottom of the hole, as shown by the drill core, is crumpled and dips at a high angle, although the overlying sandstones on the crest of the anticline are practically flat. Although the soft shale of the upper part of the Colorado has been thus crushed and crumpled, the more rigid sandstones in the lower part of the formation and in the Kootenai, like those that are exposed at the surface of the anticline, may have been strong enough to withstand the stresses that caused the deformation without crumpling and breaking. It is therefore probably in general true that the presence of crumpled shale in the larger anticlines in the belt of disturbed rocks in this region does not necessarily condemn these folds for oil prospecting.

About 15 miles off the east edge of the Blackfeet Reservation, near Kevin, Toole County, on the James Miller ranch, a boring 1,755 feet deep, sunk in search of oil, passed through the lower two-thirds of the Colorado shale and all of the Kootenai formation, and probably entered the Jurassic. This well is in the midst of a large area whose rocks lie horizontal, as shown by exposures in the vicinity and also by the Virgelle sandstone in the prominent escarpment west and north of the locality. The boring was therefore made at a place where the structure was unfavorable to the accumulation of gas or oil. Small flows of gas, however, were encountered at three horizons. The log of this well, furnished by H. C. Price, of Great Falls, Mont., was as follows:

Log of well at the James Miller ranch, in the NW. $\frac{1}{4}$ sec. 25, T. 34 N., R. 4 W.

[Elevation, 3,360 feet.]

Probable formation.	Driller's description of the rock.	Thickness.	Depth.
		<i>Feet.</i>	<i>Feet.</i>
Glacial drift.	Loam and gravel.....	40	40
Colorado shale.	Black shale.....	120	160
	Lime shell.....	2	162
	Black shale.....	163	315
	Sand (gas and water).....	5	320
	Gray-black shale.....	100	420
	Sand (gas).....	10	430
	Sandy shale.....	30	460
	Hard dark shale.....	10	470
	Black shale.....	180	650
	Gray sandy shale.....	70	720
	Black sand.....	10	730
	Sandy shale.....	40	770
	Light shale.....	80	850
	Sandy shale.....	100	950
	Black shale.....	95	1,045
	Gray sand.....	20	1,065
	Sand (gas, best flow).....	5	1,070
	Black shale.....	30	1,100
Kootenai formation.	Light shale.....	15	1,115
	Red rock.....	35	1,150
	Light shale.....	45	1,195
	Hard shell.....	5	1,200
	Hard sand.....	25	1,225
	Shell.....	5	1,230
	Sand.....	70	1,300
	Light shale.....	60	1,360
	Sand.....	30	1,390
	Hard shell.....	10	1,400
	Light shale.....	60	1,460
	Hard sand.....	40	1,500
	Hard shell.....	10	1,510
	Hard sand.....	40	1,550
	Yellow shale.....	50	1,600
	Gritty sand.....	50	1,650
	Hard shell.....	5	1,655
	Black shale.....	20	1,675
	Hard shell.....	5	1,680
Jurassic.	Limerock.....	50	1,730
	Black shale.....	25	1,755

Borings were also made just off the west edge of the reservation in three places at the base of the mountain front in the Glacier National Park (localities 1, 2, and 3, Pl. XXIV). All these borings seem to have been dry or to have struck only very small amounts of gas. The Colorado shale is the surface rock at each of these places and the greater part of the beds penetrated belong to that formation. At locality 2, near Sherburne Lake, several holes were drilled to a depth of about 1,600 feet entirely in the Colorado shale. These three places are only a few miles from the trace of the Lewis overthrust, and the whole of the Colorado shale is tilted to the west and has been much thickened by crumpling and repeated faulting. The negative results obtained at these widely scattered places along the base of the mountain front and the geologic evidence that the formations on the west edge of the reservation are much disturbed indicate that this part of the region is unfavorable for oil and gas prospecting.

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 641—K

COALS IN THE AREA BETWEEN BON AIR AND CLIFTY, TENNESSEE

BY

CHARLES BUTTS

Contributions to economic geology, 1916, Part II
(Pages 307-310)

Published January 19, 1917



WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

ILLUSTRATION.

	Page.
FIGURE 36. Map showing location of coal mines and prospects in the Pikeville quadrangle, Tenn	308

II

COALS IN THE AREA BETWEEN BON AIR AND CLIFTY, TENNESSEE.

By CHARLES BUTTS.

INTRODUCTION.

On the economic-geology map in the Pikeville folio¹ of the Geologic Atlas of the United States a strip representing ground between Bon Air and Clifty, Tenn., and lying within a space shaded to show the probable extent of workable coal beds was left unshaded, presumably because the knowledge available at the time did not warrant a positive conclusion regarding the coal resources of the area represented by the unshaded strip. The absence of shading was simply an expression of lack of knowledge, but it has been misinterpreted by some persons as a condemnation, so the area has recently been reexamined by the United States Geological Survey. It is hoped that the following notes giving the results of the examination will serve to correct any misunderstanding regarding the probable coal resources of this area that may have grown out of the use of the Pikeville map.

SECTIONS OF THE COAL BEDS.

Bon Air coal.—In an old, abandoned mine at Owens station (locality 1 on the map, fig. 36), at the level of the creek, the bed of coal mined seems to be one of the Bon Air beds. The coal was not accessible and could not be examined, but its thickness is reported to be variable and to reach a maximum of 28 inches.

In the "gulf" of Caney Fork, 1 mile south of Welch Knob (2 on fig. 36), a bed supposed to be the Bon Air is in part exposed immediately beneath the basal conglomeratic sandstone of the coal measures. The upper 2 feet 6 inches of the bed is visible, and the total thickness is reported to be 4 feet. The coal has been dug on a small scale for local supply. On Lost Creek about 1½ miles northwest of Chestnut Mountain (3 on fig. 36) the Bon Air bed is 44 inches thick, apparently all clean, hard, bright coal.

¹ Hayes, C. W., U. S. Geol. Survey Geol. Atlas, Pikeville folio (No. 21), 1895.

The Bon Air bed is probably workable as far east as Owens, though present knowledge does not justify positive assertion to that effect.

Clifty coal.—The continuity of the Clifty coal as a workable bed is uncertain. At the Clifty mines it thins out toward the north along

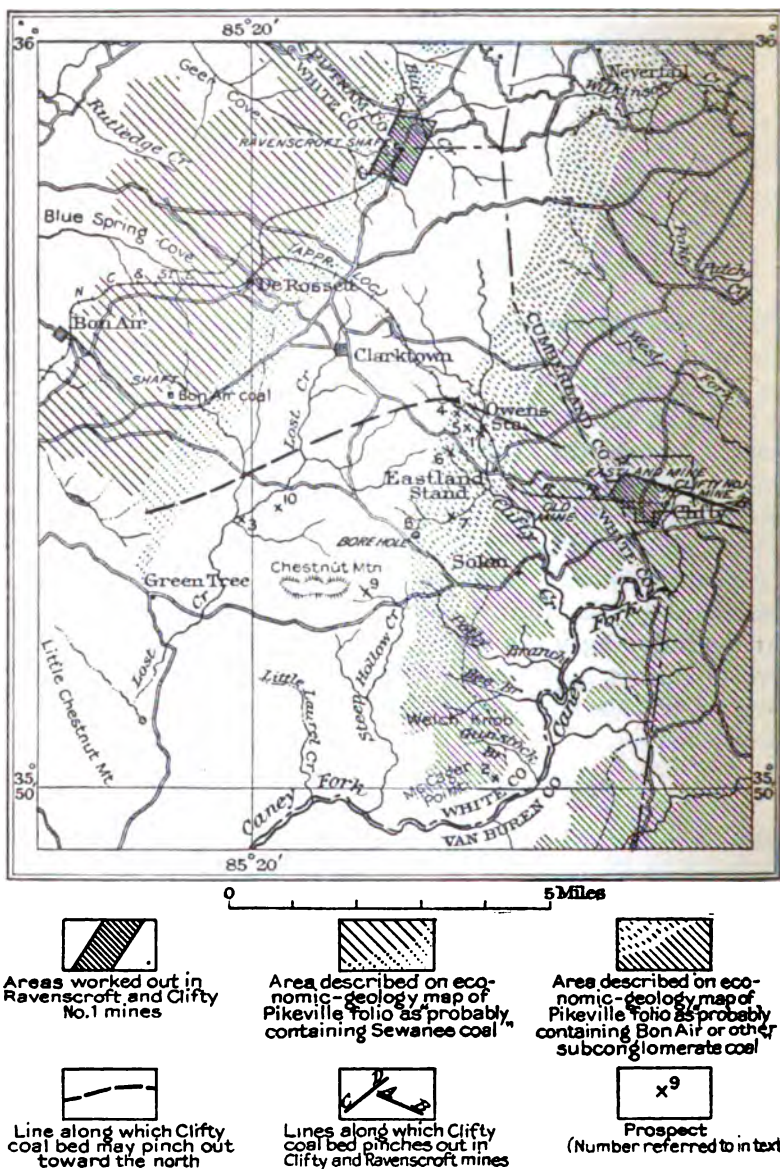


FIGURE 36.—Map showing location of coal mines and prospects in the Pikeville quadrangle, Tenn.

the line A-B on the map. It extends westward along that line as far as Owens station. West of Owens it becomes thin and is of little value.

At a prospect three-fourths of a mile west of Owens (4 on fig. 36) the section of the bed is as shown below:

Section of Clifty coal bed three-fourths of a mile west of Owens station.

	Ft.	in.
Shale roof.		
Coal.....	1	4½
Clay (exposed).....		6
Total coal.....	1	4½

A short distance west of this locality the bed is reported to split into a number of thin streaks in sandstone.

At a prospect on the side of the ridge just west of Owens (5 on fig. 36) the following measurements were obtained:

Sections of Clifty coal bed at prospect west of Owens.

	Mouth of prospect.	Ft.	in.
Shale roof.			
Coal.....		1	4

200 feet in.

Shale roof.			
Coal.....	2	0	
Coal and bone.....		4	

At a prospect about three-fourths of a mile southwest of Owens (6 on fig. 36), now inaccessible, the bed is reported to be about 30 inches thick.

About 1½ miles south of Owens (7 on fig. 36) the Clifty bed carries 5 feet of coal, as shown below:

Section of Clifty coal bed 1½ miles south of Owens.

	Feet.
Shale roof.	
Coal.....	5
Coal and bone.....	2
	7

At locality 8, three-fourths of a mile southwest of locality 7, a boring was made to the coal, which is reported to be 38 to 40 inches thick.

At a prospect pit on the old Sal Scott place, at the east end of Chestnut Mountain (9 on fig. 36), the bed is reported to be 5 feet thick. The prospect was closed and the coal was inaccessible.

On Lost Creek, 1½ miles northwest of Chestnut Mountain (10 on fig. 36), the bed has the following section in a prospect pit:

Section of Clifty coal bed 1½ miles northwest of Chestnut Mountain.

	Ft.	in.
Shale roof.		
Coal.....		8
Bone (pyritous).....	1	0
Coal.....	1	2
Bone and coal, mostly bone.....	1	0
	3	10

CONCLUSIONS.

The facts here stated constitute all that is known about the coal resources of the area represented by unshaded space on the economic-geology map in the Pikeville folio. They seem to justify the belief that the Bon Air coal underlies the area north of Caney Fork to a line drawn from Owens to Bon Air and west of a line drawn from Owens to Welch Knob. The Bon Air coal is not present, however, at the mouth of Clifty Creek just north of its junction with the river, nor on Little Laurel Creek 2 miles south of Chestnut Mountain, where the conglomerate above the coal rests upon shale that would underlie the coal if it was present. The bed may or may not extend beneath the area represented by the unshaded space on the map north of a line between Owens and Bon Air. The absence of the bed on Little Laurel Creek and at the mouth of Clifty Creek, together with its thinness and irregularity at Owens, shows that it is patchy where it is best known and suggests that it is likely to be patchy throughout the area.

The Clifty coal can reasonably be considered of workable thickness in the area southeast of a line drawn from Owens station to the opening $1\frac{1}{2}$ miles northwest of Chestnut Mountain (10 on fig. 36). It is absent in the area north of the Clifty mines (north of the line *A-B*), where it thins out and disappears. It also thins to a feather edge about a mile west of Owens station, and it is not present in the cliff at Bon Air. Its absence in these areas may be explained as follows: At Clifty the coal is in shale between two sandstones. The two sandstones converge northward and westward and finally unite on a line north of Clifty and west of Owens and somewhere between Bon Air and locality 10 (fig. 36) northwest of Chestnut Mountain, thus cutting out the shale and the included coals. The hypothetical limit of the coal is indicated by the broken line extended from the line *A-B* north of the Clifty mine. Somewhere north of the broken line in the area represented in the unshaded part of the economic-geology map in the Pikeville folio the coal evidently comes in again, for it is a thick and valuable bed at the Ravenscroft mine, at the northwest corner of that area. At the southwest angle of the Ravenscroft workings, however, the coal pinches out, as it does north of Clifty, and it is not known on the bluff west of Ravenscroft, where the conditions seem to be the same as at Bon Air.

Present knowledge, therefore, seems to justify the conclusion that two coal beds lie beneath the area represented by the unshaded space on the economic-geology map in the Pikeville folio but that the areas in which these coals are workable are patchy in distribution, so that any investment or mining in this area should be preceded by careful and thorough prospecting.

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 641—L

OIL RESOURCES OF BLACK SHALES OF THE EASTERN UNITED STATES

BY

GEORGE H. ASHLEY

Contributions to economic geology, 1916, Part II
(Pages 311-333)

Published February 8, 1917



WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

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OIL RESOURCES OF BLACK SHALES OF THE EASTERN UNITED STATES.

By **GEORGE H. ASHLEY.**

PURPOSE AND SCOPE OF INVESTIGATION.

It has long been known that black shales owe their color to bituminous or carbonaceous matter and that most such shales, if heated, will yield gas, oil, and other by-products. For many years such shales have been distilled for oil in Scotland and other European countries. The Scotch distilleries are reported to have been of the greatest aid to England during the present war in supplying the oil-burning ships of her navy, thus saving the excessive cargo rates on oil from America. It has long been recognized in this country that the time would come when the decline of yield in the oil fields would lead to tests of the black shales as a possible source of oil. The recent great increase in the use of light oils in internal-combustion engines has renewed interest in the black shales and has led to definite exploratory work on certain oil shales of the West and preliminary studies on the black shales of the East. Preliminary reports on the results of the studies of the western oil shales by the United States Geological Survey have already appeared.¹

In 1914 the writer visited and sampled black shales at a number of places east of the Mississippi River. Later other samples were obtained in Pennsylvania by R. V. A. Mills and William R. Cameron, in Ohio by Wilbur Stout, in Illinois by Wallace Lee, in Kentucky and Indiana by Charles Butts, and in Tennessee by F. R. Clark. The samples are described and the results of their distillation given in this report. The writer's samples were all cut on the outcrop with an army adz. First a trench was dug through the weathered surface of the shale until the hard surface of the apparently unweathered shale had been reached. Then a shallow trench the width of the adz was cut in the unweathered rock, and

¹ Woodruff, E. G., and Day, D. T., Oil shale of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 581, pp. 1-21, 1915. Winchester, D. E., Oil shale in northwestern Colorado and adjacent areas: U. S. Geol. Survey Bull. 641, pp. 139-198, 1916 (Bull. 641-F).

the material thus obtained was broken down and quartered after the manner of taking coal or other samples, until a 5-pound sample was obtained, and this was sent to Washington in a canvas bag. In most places where samples were taken the soft, weathered portion of the shale proved to be very thin and the underlying rock very firm and tough. In a few places the shale was exposed as a vertical face, with little or no weathered material on the face.

OCCURRENCE OF THE SHALES.

The black shales of the Eastern States are mainly at one general horizon, in the Upper Devonian or possibly in part lower Carboniferous, which extends from New York to Alabama and westward to Mississippi River. Other extensive deposits of black shale occur at one or more horizons in the lower part of the Devonian and at one horizon in the Ordovician. In addition, black shales overlie some of the coal beds, especially certain beds in the eastern interior coal field.

The principal body of black shale is known as the Chattanooga, New Albany, or Ohio shale. This bed underlies the eastern coal fields and crops out in a long line from central Alabama northeastward through Tennessee and Virginia and all around the Nashville Basin, in central Tennessee. West of the Appalachian coal field its outcrop extends from north to south across central Ohio, passing close to Columbus and reaching Ohio River near Vanceburg. Thence the outcrop makes a loop through central Kentucky, past Lebanon, and northward to Louisville, from which it stretches in a broad belt northwestward across Indiana, past Indianapolis nearly to Chicago. From this western belt of outcrop the shale extends eastward under eastern Ohio and underlies nearly all of Kentucky except the area within the loop described and all of Indiana west of the outcrop. Samples of this shale were cut at Cumberland Gap, Rockwood, and Chattanooga, Tenn., on the eastern front of the coal field; at Bakers station and near Newsom station, Tenn., in the Nashville dome area; and near Columbus, Ohio, and at New Albany, Ind., on the western outcrop.

The Middle and Lower Devonian of New York, Pennsylvania, Maryland, and West Virginia contain thick beds of dark shale that is locally black and fissile. Samples were cut near Hancock station, W. Va., in the black layers of the Onondaga shale member of the Romney shale.

Black shales overlying coal beds were sampled near Boonville, Ind., where the No. 5 bed was being stripped by a steam shovel, and at Springfield, Ill. Few of the black shales over the coals have a thickness of more than 5 feet.

SAMPLES OF THE SHALES.

INDIANA.

Samples were cut at two places in Indiana, at New Albany in the New Albany black shale, which is there about 100 feet thick, and northeast of Boonville, where black shale makes the roof of the No. 5 coal.

Sample 1 was cut in the upper part of the New Albany black shale in the bank of Ohio River at the mouth of Falling Run, just below New Albany. The sample represents a 10-foot section, of which the upper 5 feet was taken in the face of a vertical cliff on the east side of the run and the lower 5 feet from the shelving exposure just below. About 20 feet of black shale, carrying many thin streaks of hard, apparently limy shale, is exposed here, of which the sample represents the lower 10 feet. The shale in the vertical face was very tough. The shale in the shelving river bank breaks out into quadrangular plates 2 to 4 inches thick, which may be as much as 3 or 4 feet in length or width. The edges follow jointing planes that run S. 65° W. and S. 30° W.

Sample 2 was cut in 1915 by Charles Butts at the same place as sample 1.

Sample 3. Many large boulders or concretions of the black shale occur on the river bank at New Albany. The outside portions of these boulders for a variable distance in are weathered to a gray color. The central portions are still a dark bluish black and give off a marked oily odor when broken. Sample 3 was made up of fragments from the black centers of a number of these boulders. The boulders appear to be concretionary.

Sample 4. At low water the immediate bank of the Ohio under the Kentucky & Indiana Railroad bridge at New Albany is a gentle slope, exposing about 25 feet of New Albany black shale. A trench 15 feet long and 6 to 10 inches deep was cut in this rock near the upper edge of the exposure. Sample 4 was cut in the bottom of this trench and represents a vertical thickness of about 5 feet.

Sample 5 was cut just above the Kentucky & Indiana Railroad bridge at New Albany in 1915 by Charles Butts.

Sample 6. A short distance northeast of Boonville the No. V coal bed is being stripped on a large scale by the Ohio Valley Coal Co. The coal is from 6 to 9 feet thick, and over it is 4 feet of black shale. Sample 6 was cut from the full thickness of the shale where freshly dug by the steam shovel. The black shale is overlain by 9 feet of drab to dark shale, 10 inches of limestone, 6 feet of light-gray shale, and 10 feet of light-brownish clay and soil. This sample should be as unweathered as any to be obtained by such stripping.

Sample 7 was obtained from a 5-foot cut in the lower part of the 9 feet of dark shale immediately overlying the shale cut for sample 6.

The sample was cut to determine if the dark shales carried even a small amount of oil.

Sample 8 was obtained from a second cut in the black shale immediately over the coal at a point near the power house at the upper end of the stripping. At this place the black shale is 6 feet thick and is overlain by 3 to 4 feet of gray shale and 10 feet or less of clay and soil. The black shale at this point had been exposed for many months, if not a year. It is of interest, however, to note that notwithstanding this fact and the small thickness of covering, the sample gave a larger yield of oil than sample 6. It may be noted that this shale is dead black on the fresh surface instead of having the chocolate-brown color of many of the shales sampled.

ILLINOIS.

Sample 9 was obtained from the black shale roof of No. 5 coal at the East Capitol mine, in Springfield, Ill., by breaking up a number of large blocks of black shale that had been removed from the mine about a week before in cleaning up a roof fall. Only the "hearts" of the blocks were taken to avoid including any shale that might have been weathered along the joints after the removal of the coal. The breaking down of the shale would naturally follow the joints, and the joint faces would form the outside surfaces of the blocks. The shale appeared to be massive, nonfissile, and blackish drab.

Sample 10 was cut by Wallace Lee in the roof shales of the No. 5 coal at the Saline mine, Gallatin County.

KENTUCKY.

Sample 11 was obtained by Mr. Butts in 1915 from an 8-foot cut in the New Albany black shale at the west end of the canal at Louisville.

Sample 12, taken by Wallace Lee, consists of the so-called coal rash or mother of coal associated with the coal bed at the Barnaby mine, Crittenden County.

Sample 13, also taken by Wallace Lee, represents carbonaceous shale that lies 50 feet above the Bell coal at Caseyville, Ky.

OHIO.

On the recommendation of Prof. J. A. Bownocker, State geologist of Ohio, samples were cut in the Ohio shale in a ravine at Glen Mary, 8 miles north of Columbus. The cuts were made in the nearly vertical face of a wash, about 200 yards below the pike.

Sample 14 represents a cut 5 feet long. The shale, after the removal of 6 inches of weathered rock, broke out in small chips, which had a drab color outside or where cut but black cross sections where broken.

Sample 15 represents a 3-foot cut at the same place but lower in the section. Instead of taking all the material, it was prepared by using only the "heart" of the largest chips, in the hope of obtaining a sample more nearly representative of the rock away from the outcrop. About 15 feet of shale shows at this point.

Sample 16. The Sunbury shale in Ohio is in the lower part of the Carboniferous system, overlying the Berea sandstone, one of the principal "oil sands" of the State. Sample 16 was cut by channeling from the middle of the Sunbury by Wilbur Stout, at Columbus, on the Broad Street pike near Black Lick Creek.

Sample 17 was cut from the base of the Sunbury shale by Mr. Stout on Rock Fork, above the covered bridge northeast of Gahanna. The shale is 6 to 8 feet thick and was sampled by channeling.

PENNSYLVANIA.

Sample 18. The Upper Kittanning coal is a cannel coal at many places in Pennsylvania. Near Cannelton, Beaver County, a deposit of cannel coal at this horizon occupies a narrow, oblong oxbow channel, 5 miles in length and 600 feet wide. The coal is 15 feet thick in the center of the basin, but thins to 2 feet or less at the edges. It is underlain by 1 foot of bituminous coal. Over the coal is a black shale that in places in the mine has broken down for several feet. Sample 18 was cut from the edge of one of these breaks, where the shale had been exposed to the air for 60 years or more. The black shale roof may have a much greater horizontal extent than the minable coal beneath. I. F. Mansfield, who has mined the coal here for many years, estimates that there is a thousand acres of shale from 3 to 5 feet thick.

Samples 19 to 24 were taken by R. V. A. Mills in Butler County but in connection with the geological survey of the Butler quadrangle. Probably none of these samples represents sufficient thickness to indicate a workable deposit, but they are of interest as showing what may be obtained from such shales.

Sample 19 represents a cannel-like shale, 1 foot thick, underlying 16 inches of thin-bedded black shale and overlying 15 inches of mottled clay that in turn overlies the Lower Freeport coal 2 feet thick, in the southwest corner of Clay Township. The yield from this sample suggests a true cannel coal.

Sample 20 was taken from the dump of an old mine 1 mile north of Muddy Creek, three-quarters of a mile west of the Bessemer Railroad, 1 mile northwest of Queen Junction. The material is probably a low-grade cannel coal, apparently about 2 feet thick.

Sample 21 represents 1 foot of cannel-like shale or cannel coal in a weathered outcrop beside the road in the southwest corner of Clay Township, 1,000 feet west of the Butler and Mercer Pike.

Sample 22 represents 1 foot of cannel shale and 3 inches of cannel coal from the unmined roof over the Upper Freeport coal in the Muntz mine, just south of Butler.

Sample 23 was gathered from the dump of an abandoned mine on the north bank of Swamp Run, on the eastern edge of the Zelenople quadrangle. The bed is reported to have been lenticular, to have had a maximum thickness of 6 feet, and to have consisted entirely of black shale at the Lower Freeport horizon.

Sample 24 represents the lowest 10 feet of a black shale over the Upper Freeport coal exposed on the old State road on the hill just south of Butler. The upper part of the shale grades into sandy shale.

TENNESSEE.

The Chattanooga black shale underlies nearly all the upland region of middle Tennessee. It crops out along the foot of the escarpment east of the coal field and near the foot of the escarpment facing the Nashville Basin. West of the Nashville Basin and along Tennessee River are many areas where the black shale underlies gentle slopes. It was sampled at Cumberland Gap; at Rockwood, where the writer was taken to the best exposures by Mr. George E. Sylvester, formerly State mine inspector; at the south end of the ridge south of Alton Park, near Chattanooga, in some old workings for "phosphate"; at Bakers station, on the Louisville & Nashville Railroad, north of Nashville; and at the top of a quarry about halfway between Newsom and Pegram stations, on the Nashville, Chattanooga & St. Louis Railway, west of Nashville.

Samples 25 and 26 were taken at Cumberland Gap in the railroad cut at the mouth of the tunnel. At this point a fault crosses the mountain and the shales are much crushed and contorted. Where sample 26 was cut nearly a quarter of the rock is sandy and calcareous material. All the rock has been crushed until it mines out in slickensided flakes. These samples do not afford a fair test of what this shale should yield away from the fault.

Sample 27. The samples obtained at Rockwood give a better test of the oil contents of the Chattanooga shale along the front of the Cumberland escarpment. Sample 27 was taken from a 2-foot cut at a corner one block north of the main street, near the railroad, where the shale has a high dip and is much crumpled.

Sample 28 represents a 5-foot cut at a point north of Rockwood and west of the iron mines. The shale here also has a high dip and is much crumpled.

Sample 29. A connecting spur built northeast of Rockwood station about 1900 cut through the black shale, which at this point has a dip of about 15°, but is contorted so as to resemble material having cone

in cone structure. Sample 29 represents a 3-foot trench at the west end of this cut.

Samples 30 and 31. Some years ago a mine was opened in the Chattanooga black shale a few miles south of Chattanooga, close to the road at the south end of a ridge extending south from Alton Park. The shale at this place is only 6 feet thick. It is underlain by 10 feet or more of light-drab clay and overlain in order by 18 inches to 2 feet of cream-colored clay, 6 inches to a feather edge of dark-drab to black shale, 18 inches of drab shale, 2 feet 6 inches of cream-colored cherty clay, and 20 feet or more of gray chert. The rocks at the mine have a dip of about 12° . Sample 30 was cut 30 or 40 feet from the entrance to the mine and sample 31 about 15 feet from the entrance. The black shale here is not typical. Sample 30, for example, resembles a hard grayish-black massive to fissile clay.

Samples 32 to 34 were taken at Bakers station, where the Louisville & Nashville Railroad crosses the Chattanooga black shale in descending from the highland rim to the Nashville Basin. The top of the black shale at this point rises above the railroad track a short distance above the station, and the whole of it is exposed a short distance below the station. The shale has a thickness of 27 feet, of which the upper 11 feet is jointed and "sheety"—that is, it breaks out in large thin sheets—and the lower 16 feet is fissile. Over the black shale is 1 foot of green shale with concretions (Maury glauconitic member of Ridgetop shale), then 30 feet or more of characteristic Ridgetop shale. The railroad cut is only a few years old, having been made in a realignment and regrading of the road. The dip is less than 1° .

Sample 32 includes 5 feet of the top of the bed where it reaches that height above the drain. Part of the rocks come out in plates one-fourth to one-half inch thick, but most of it breaks out as irregular massive chunks several inches thick. In places partly weathered pieces indicate that this massive phase weathers into the characteristic thin flakes. The rocks were shattered by blasting in making the cut, and the action of weathering has penetrated along the fracture planes to a slight extent. The top 18 inches has a chocolate-brown streak where cut across, but the next 30 inches gives a blackish-gray to grayish-black streak.

Sample 33, taken at the west end of the bluff below the station, includes 5 feet of a section starting 6 feet below the top of the formation. The shale is hard and massive and of a dark chocolate color. It is strongly jointed, and the long or face joints run N. 63° W. and the short or butt joints N. 48° E.

Sample 34 represents 5 feet in the middle of the lower 16 feet of thinly laminated shale. The color is a grayish black. On the joint faces the shale has the appearance of a dull-black clay.

Sample 35. Around Newsom and between Newsom and Pegram are a number of large limestone quarries. At one of these, about

halfway between the two stations, the limestone is overlain by 10 feet or more of black shale, which is exposed only at the top of the vertical face of the quarry. Sample 35 was taken at one side where the black shale reaches the slope of the hill and is obviously weathered, as after a preliminary trench several feet deep had been cut the material taken out below it was soft.

Sample 36 was taken at the same place as sample 35, but from the vertical face of the shale at the top of the quarry by cutting steps down to a slight quarry shelf. The shale, though dull brown and weathered, had the usual firmness.

Sample 37 was cut by F. R. Clark and represents 6 inches of bituminous shale overlying the cannel coal at Newcomb, Tenn.

WEST VIRGINIA.

Samples 38 to 42 were cut in the black shale of the Onondaga member of the Romney shale, of Middle Devonian age, at a locality well east of the coal fields, in what has been called the Appalachian Valley. In this region the rocks have been closely folded, and it was therefore thought that the oil in the black shale must have been driven out and that the black color was due entirely to the residue of carbon. The distillation tests confirm this opinion. The samples were cut on the West Virginia side of the Potomac, near Hancock station. In the large cut half a mile above the station the rocks dip 40° S. 45° E. The section shows 25 to 30 feet of black fissile shale, 25 feet of olive-drab shale, and 40 feet of grayish-black shale with rusty joint faces, underlain by the Oriskany sandstone.

Sample 38 represents a 40-foot cut in the black fissile shale about 100 feet above the railroad track. This shale was cut out in pieces ranging from plates 1 inch thick down to thin scales. The plates are rusty on the bedding faces but black on cross faces when broken.

Sample 39 was taken from a 5-foot cut at a bold outcrop of the olive-drab shale.

Samples 40 and 41 represent two cuts in the grayish-black shale.

Sample 42 was cut in grayish-black shale beside the road to Berkeley Springs, about a quarter of a mile from the station.

DISTILLATION TESTS.

Two sets of tests of the writer's samples were made under the direction of David T. Day by means of an electric furnace or a gas heater, in which the temperature was raised slowly until all the oil appeared to have been driven off, when the temperature was raised further to drive off the remainder of the gas. The first series of tests were of a preliminary nature and were made at the Geological Survey by J. A. Dorsey; the second series were made at the Bureau of Mines by C. R. Bopps. The samples collected in 1915 were tested

at the survey by D. E. Winchester. In order to show how the yields of these samples compare with the yields of cannel coal, results obtained from a number of cannel coals that were distilled at the same time and in the same manner are included in the subjoined table. These coals are described in a bulletin on cannel coal to be published by the Survey. With the possible exception of the Cannelton cannel they are not as rich as many of the Kentucky cannels.

Tests of black shale and of some cannel coals from the eastern United States.

[By David T. Day, except those marked *, which were made by D. E. Winchester.]

Sample No.	Locality.	Preliminary test.			Final test.				
		Amount used (grams).	Oil obtained (cubic centimeters).	Yield per short ton (gallons).	Amount used (ounces).	Yield per short ton.			
						Oil (gallons).	Water (gallons).	Gas (cubic feet).	Ammonia (pounds).
SHALE.									
1	New Albany, Ind.	100	3	7	6	3.5	5.6	719	0.08
2	do.				6	9.1	4.2	958	0
3	do.	100	7	16	6	11.2	7	2,043	.15
4	do.	100	3	7	6	4.9	8.4	1,097	0
5	do.				6	11.9	6.3	1,197	0
6	Boonville, Ind.	100	3	7	6	14	11.2	2,522	.97
7	do.	100	0	0	6	None.	9.8	479	0
8	do.	100	9	21	6	15.4	12.6	2,922	.61
9	Springfield, Ill.	100	5	12	6	11.9	9.8	2,186	.65
*10	Gallatin County, Ill.				8½	16	7.5	Not det.	3.44
11	Louisville, Ky.				6	11.2	4.2	1,016	0
*12	Crittenden County, Ky.				8½	14	12	Not det.	2.58
*13	Caseyville, Ky.				8½	Trace.	Trace.	Not det.	2.28
14	Glen Mary, Ohio	100	3	7	6	7.7	5.6	1,199	.11
15	do.	100	4	9	6	5.6	5.6	958	0
*16	Columbus, Ohio.				8½	4	18	Not det.	1.02
*17	Gahanna, Ohio.				8½	11	18	Not det.	1.61
18	Cannelton, Pa.	100	12	28	6	27.3	9.1	2,906	.92
*19	Clay Township, Pa.				8½	45	15	Not det.	3.72
*20	Queen Junction, Pa.				8½	43	13	Not det.	4.99
*21	Clay Township, Pa.				4½	34	18	Not det.	5.21
*22	Butler, Pa.				8½	24	11	Not det.	9.43
*23	Zellenople quadrangle, Pa.				4½	18	10	Not det.	2.53
*24	Butler, Pa.				8½	1	11	Not det.	1.06
25	Cumberland Gap, Tenn.	100	1	2	6	1.4	8.4	598	.28
26	do.	100	1	2	6	Trace.	3.5	230	0
27	Rockwood, Tenn.	100	4	9	6	7.7	9.8	1,488	.15
28	do.	100	3	7	6	5.5	7	1,128	.17
29	do.	100	1	2	6	2.8	14	1,077	0
30	Alton Park, Tenn.	100	0	0	6	Trace.	14	835	0
31	do.	100	Trace.	0	6	7	9.1	1,437	0
32	Bakers station, Tenn.	100	4	9	6	9.1	4.2	1,916	.33
33	do.	100	3	7	6	9.1	4.9	1,485	.10
34	do.	100	3	7	6	6.3	8.4	1,557	.10
35	Newsum, Tenn.	100	0	0	6	None.	12.9	835	.15
36	do.	100	3	7	6	4.2	8.4	835	.21
*37	Newcomb, Tenn.				8½	21	2	Not det.	5.07
38	Hancock station, W. Va.	100	0	0	6	Trace.	7	538	0
39	do.	100	0	0	6	7	9.8	696	1.00
40	do.	100	0	0	6	Trace.	11.2	393	0
41	do.	100	0	0	6	7	8.4	230	0
42	do.	100	0	0	6	None.	7	319	0
CANNEAL COAL.									
	Altoona mine, Indiana County, Pa.	100	10	24	6	20.3	7.7	4,790	5.57
	Bostonia mine, Armstrong County, Pa.	100	17	40.8	6	33.6	7	5,029	5.37
	Pine Run No. 1, Armstrong County, Pa.	100	14	33.6	6	25.2	9.8	5,029	5.06
	Pine Run No. 3, Armstrong County, Pa.	100	8	19	6	31.5	8.4	4,311	3.68
	Cannelton, Beaver County, Pa.	100	21	50.4	6	37.3	10.5	5,268	2.24

According to these figures the Devonian black shale can be expected to yield not over 10 or 12 gallons of oil, 2,000 cubic feet of gas (as a by-product), and one-third of a pound of ammonia to the ton. Shales that are highly folded yield less oil or none at all, though the first sample cut at Rockwood, Tenn., gave an unexpectedly high result, notwithstanding the folded condition of the rocks at that place. Later experiments show that by distillation under steam the yield of ammonia may be increased above the figures given in the table.

It seems possible, if not probable, that many of the apparently unweathered samples have lost some or much of their oil. The black shale was found to be unexpectedly tough, so that the attempt to cut samples in the same manner as coals or clays are sampled proved extremely slow, and, moreover, doubt remained as to whether the shale face had been trenched deeply enough to be beyond the reach of surface weathering. This toughness will have a marked influence on the cost of mining. At the stripping near Boonville it has been found that the steam-shovel teeth ordinarily used wear out at once in digging the black shale, so that it is necessary to use special teeth of manganese steel, and even these last only two weeks.

OIL CONTENT.

To give some idea of the amount of oil in this shale a few figures are given for the body of black shale in southwestern Indiana. The weight of this shale is not known. Common shale weighs about 160 pounds to the cubic foot, or practically twice as much as coal, but this weight is reduced by the presence of hydrocarbons, and high-grade oil shales weigh as little as 100 pounds to the cubic foot. If a weight of 130 pounds to the cubic foot is assumed, it will require about 15.4 cubic feet of shale to weigh a short ton. If 1 ton of shale is assumed to yield 10 gallons of oil, 100 cubic feet of shale may be assumed to yield 64.9 gallons, or say roughly $1\frac{1}{2}$ barrels (of 42 gallons).

The following table gives some measurements of the thickness and depth to the top of the black shale at places in Indiana, as obtained in drilling oil wells:

Reported thickness and depth of New Albany black shale in Indiana.

Locality.	Thickness.	Depth to top
	<i>Feet.</i>	<i>Feet.</i>
Albion, Noble County.....	85+	a 375
Bloomington, Monroe County.....	120	790
Bridgeport, Marion County.....	124	140
Brownstown, Jackson County.....	147	318
Columbus, Bartholomew County.....	87+	26
Crawfordsville, Montgomery County.....	80	550
Fowler, Benton County.....	92	a 280
Kentland, Newton County.....	100+	a 100
La Fayette, Tippecanoe County.....	120	100
Martinsville, Morgan County.....	120	408
New Albany, Floyd County.....	104	80
Oxford, Benton County.....	100+	a 385
Remington, Jasper County.....	85	5
Rockville, Parke County.....	102	1,044
Salem, Washington County.....	103	627
Seymour, Jackson County.....	130+	a 75
Thornton, Lawrence County.....	87	303

a Roof of black shale is glacial clay.

These figures give an average thickness of not far from 100 feet. As exposed from Jeffersonville to and beyond New Albany, the shale shows little variation from top to bottom. It is not certain that the black shale as reported in the well logs is all of the same character. In fact, some of the exposures of the "black shale" in the northern part of the State indicate that the shale in that region is not uniformly black, as is shown by the following section:¹

Section of "black shale" at Delphi, Ind.

	Ft.	in.
Drift.....	7	0
Bluish-black shale, sheety and tough.....	45	0
Drab-grayish, slightly sandy shale.....	4	6
Band of gray concretions.....	6	14
Drab sandy shale.....	10	6
Bluish-gray sandstone.....	4	10
Drab sandy shale.....	5	6
Covered.....	8(?)	
Devonian limestone.		

The log of a deep well at Terre Haute, believed to have gone through this black shale, shows the following beds:

Partial record of deep well at Terre Haute, Ind.

	Thickness	Depth.
	<i>Feet.</i>	<i>Feet.</i>
Blue shale.....	40	1,622
Black shale.....	15	1,637
Red shale.....	5	1,642
Black shale.....	15	1,657
Limestone.....	5	1,662
Black shale.....	5	1,667
Limestone.....		

¹ Kindle, E. M., Indiana Dept. Geology and Nat. Res. Twenty-fifth Ann. Rept., p. 533, 1900.

It is a very moderate assumption to place the average thickness of the oil-yielding rock at say 30 feet, of which it might be possible to mine out one-half, or 15 feet. The New Albany black shale underlies about 16,000 square miles. If 15 cubic feet of rock weighs 1 ton and yields 10 gallons of oil, 10 gallons of oil should be obtainable for every square foot of this area in southwestern Indiana. As a square mile contains roundly 28,000,000 square feet, the yield would be 280,000,000 gallons or nearly 7,000,000 barrels of oil to the square mile, or say 100,000,000 barrels for the total area underlain by the shale in southwest Indiana.

FUTURE DEVELOPMENT.

If it costs as much to mine a ton of shale and distill the oil from it as it does to mine a ton of coal, say \$1 (as a matter of fact the cost is likely to be higher), a barrel of crude oil obtained in this way will cost about \$4.20. This estimate assumes that the gas yielded is used in the distillation of the oil and takes no account of the value of by-products nor of the possibility that the oil may yield products of higher value than the crude oils now obtained by drilling.

At present interest in the mining of the eastern black shales as a source of oil must confine itself to localities where one of three conditions is met. The shale can be utilized, first, where it outcrops in a position to permit mining on a large scale by steam shovel at a minimum cost; second, where coal that is overlain by bituminous shale is being stripped; and third, where a coal bed that is being mined has a black shale roof that comes down and must be removed from the mine in large amounts. Of these the second condition seems to offer the best opportunity for a trial plant, as the overlying black shale must be removed in mining the coal. At such pits it would require only that another shovel be installed to lift the shale, or the small shovel now used to lift the coal could be used to lift the black shale first. This black shale over the coal appears to have the advantage of a higher oil yield. Where the roof shale is as rich as at Cannelton, Pa., it may pay to mine the shale with the coal.

ANALYSES.

In the Twenty-first Annual Report of the Department of Geology and Natural History of Indiana Hans Duden gives two analyses of black shale obtained at New Albany, and as that report is now out of print, they are quoted here:

Analyses of black shale from New Albany, Ind.

[By Hans Duden.]

	1	2
Water expelled at 100° C.	0.50	0.56
Water expelled at 100° C. during 4 hours	14.16	14.30
Volatile organic matters	9.30	23.60
Fixed carbon	9.30	9.30
Fixed organic matters	30.53	65.43
Silica	25.30	8.32
Silicates insoluble in HCl	.09	.09
Pyritic iron and alumina *	.12	.12
Ferric oxide		2.08
Calcium oxide		
Magnesium oxide		
Sulphur	100.00	100.00

* The amount of pyrite and alumina changes considerably in different layers. This piece had 10.367 per cent iron pyrite and 14.933 per cent alumina.

In the same report Duden gives the results of experiments in making illuminating gas from the shale, using as a retort a 4-inch pipe 6 inches long, capped at both ends and connected by a $\frac{3}{4}$ -inch pipe with washing and refining apparatus.

Gas produced from black shale and Pittsburgh coal.

	Gallons.
5 pounds of Pittsburgh coal	105
8.5 pounds of black slate	45
8.5 pounds of black slate, Ohio banks	50
8.5 pounds of black slate, Falling Run banks	65
15 pounds of freshly broken slate	105
15 pounds of the same after exposure to air for 14 days	100

He also quotes from a letter describing an experiment in the production of gas at the New Albany Gas Light & Coke Co.'s plant:

I carbonized 3 tons of the New Albany black slate and obtained a yield of 2.20 cubic feet per pound of 22-candlepower gas. Ordinary unenriched coal gas is about 18 candlepower. The quality of gas, therefore, is better and the yield 45 per cent of that obtained from Pittsburgh coal. Of the amount of oil or tar obtained I know nothing, as I did not make any measurements. The slate does not materially change its color or form by being carbonized. The residue contains much sulphur and, so far as I know, is useless for fuel. I made no scientific test. With the arrangement we have for making gas, it would not pay us to use the slate, even though we could obtain it for nothing. The slate was obtained from near the exposed surface of a creek bottom, and I am sure that if a sample was gotten at a greater depth, a much better yield of gas would be obtained.

Duden then describes the oil obtained in his experiments:

Crude oil obtained by atmospheric pressure from the slate exhibits a black coloration, has a very bad smell, and is very difficult to refine. In oil obtained with stills provided with a vacuum pump the vapors are removed from the hot still walls as quickly as formed. At the same time the temperature necessary

to form the vapors is materially lowered (about 100° C.). A vacuum of 15 inches gave very good results. The oil is nearly colorless and without much smell. By leading into the still a small amount of steam and the vacuum apparatus left as in the last case, then in the watery part of the distillate ammonia was increased materially and can be used for manufacturing sulphate of ammonia.

GOVERNMENT INVESTIGATIONS.

In 1916 Mr. Winchester continued his studies of the oil shale in the Uinta Basin of Utah, and it was planned that C. F. Bowen should examine the black shale in southwestern Montana, near Dillon. In addition to these studies, samples of black shales are being collected by other members of the Survey as opportunity offers and tested by Mr. Winchester.

In addition to this work by the Geological Survey, the Bureau of Mines proposes to erect a shale retort of the Del Monte type in the navy yard at Washington, D. C., for the purpose of carrying on preliminary investigations of the commercial possibilities of oil shales. This work will be under the direction of David T. Day. If the results justify further investigation on a large scale, the bureau will probably erect a large retort, with a capacity of possibly 500 pounds, at either the petroleum experiment station at San Francisco or the Pittsburgh station, for the purpose of obtaining complete information upon the value and possible by-products to be derived from the distillation of shale. This work will be predicated upon the results of the distillation of shale in other countries. The bureau contemplates sending an expert to Scotland to study the Scottish practice at first hand.

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